PB 187 393

PROTOTYPE FLY ASH MONITOR FOR INCINERATOR STACKS

Walter Romanek, et al

ITT Research Institute
Chicago, Illinois

25 September 1968

CLEARINGHOUSE
FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION

Distributed . . . 'to foster, serve and promote the nation's economic development and technological advancement.'

U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

This document has been approved for public release and sale.

Report No. IITRI-C8088-8
(Final Report)

PROTOTYPE FLY ASH MONITOR FOR INCINERATOR STACKS

American Public Works Association
Chicago, Illinois

Report No. IITRI-C8088-8
(Final Report)

PROTOTYPE FLY ASH MONITOR FOR INCINERATOR STACKS

March 1, 1966 through August 1, 1968

Prepared by

Walter Romanek

Meryl R. Jackson

Alvin Lieberman*

Submitted by

IIT Research Institute
Technology Center
Chicago, Illinois
60616

for

American Public Works Association
1313 East 60 Street
Chicago, Illinois
Attention: Mr. Herbert Poertner

*Now with Royco Instruments, Inc., Palo Alto, California

Copy No.___

September 25, 1968

PROTOTYPE FLY ASH MONITOR FOR INCINERATOR STACKS

ABSTRACT

A prototype monitor for particulate emissions from municipal incinerators was designed, built and field tested.

In operation, the instrument is installed on the stack some distance above the base to ensure the monitor's presence in a region of laminar flow. The monitor samples a predetermined quantity of stack gas either isokinetically or at a known velocity, separates the particulate from the gas by means of a cyclone, and measures the amount of particulate collected using a beta gauge. For each sample, the time of sampling and beta attenuation is printed out on a paper tape at some convenient location at ground level.

It was concluded that the design concept is suitable for unattended monitoring operations. It was shown that the instrument measures stack dust loading under varying furnace operating and atmospheric conditions, and that automatic isokinetic sampling, while feasible, was not an essential requirement for adequately following stack loading.

TABLE OF CONTENTS

	Page
Abstract	iii
I. Introduction	1
II. General Description of the Monitor	1
III. Monitor Design and Operation	5
IV. Field Test Sites	16
V. Results	22
VI. Discussion of Results	23
A. General Discussion	23
B. Milwaukee Tests	37
C. Chicago Tests	43
VII. Recommendations	46
VIII. Conclusions	47
Acknowledgement	49
Appendix A - Field Test Instrument Operation Data	A1
Appendix B - Operating Manual	B1
Appendix C - Independent Dust Emission Test Methods	C1
Appendix D - Monitor Purchase and Operating Cost Estimate and List of Manufacturers	D1
Appendix E - Description of Electronic Functions	E1
Appendix F - Construction Drawings	F1

LIST OF TABLES

Page

TABLE

1 Summary of Instrument Operation 24

2 Comparison with Independent Tests, MCDAPC 25

3 Comparison of Instrument Operation and Independent Tests of MCDAPC 26

4 Comparison with Independent Tests, Chicago Thimble Tests 27

5 Comparison with Independent Tests, Chicago Filter Tests 28

LIST OF FIGURES

Page

FIGURE

1 Stack Installation of the Monitor 2

2 Schematic of Instrument Operation 3

3 Motorized Valve 9

4 Dilution System 12

5 Interlocking Flow System 13

6 Back Flush 14

7 APWA Fly Ash Monitor 18

8 Monitor Installed on Southwest Incinerator, Chicago 19

9 Stack Set Up at SW Incinerator 20

10 Instrument Operation v. Time, April 30 29

11 Instrument Operation v. Time, May 6 30

12 Instrument Operation v. Time, May 12 31

13 Instrument Operation v. Time, May 14 32

14 Instrument Operation v. Time, May 17 33

15 Comparison with Independent Tests in Milwaukee 39

16 Comparison with Independent Tests in Chicago 45

PROJECT MANAGEMENT

PROJECT DIRECTOR:

Mr. Herbert Poertner
Director of Research and General Manager
APWA Research Foundation

PROJECT OFFICER FOR UNITED STATES PUBLIC HEALTH SERVICE:

Mr. John Nader
National Center for Air Pollution Control
Cincinnati, Ohio

PRINCIPAL INVESTIGATORS:

Mr. Alvin Lieberman
IIT Research Institute
(Currently with Royco Instruments, Inc., Palo Alto, Calif.)

Mr. Meryl Jackson
IIT Research Institute

PROJECT STEERING COMMITTEE:

Mr. Samuel M. Clarke, Chairman

Mr. F. Doe

Mr. M. Feldman

Mr. W. S. Foster

Mr. B. J. Geisheker

Mr. L. C. Lovell

Mr. A. Michaels

Mr. J. Nader

Mr. M. A. Noel

Mr. F. R. Rehm

Mr. G. W. Shoemaker

This project was funded jointly by APWA, USPS, and state and local governments.

PROTOTYPE FLY ASH MONITOR FOR INCINERATOR STACKS

I. INTRODUCTION

This is the final report of project C8088 to develop, design, build, and field test a prototype instrument to automatically sample and evaluate fly ash emissions from municipal incinerators. Principally this report deals with the field tests of the instrument and interpretation of the data obtained in the field. Recommendations are made for future use of such an instrument. Other aspects of this project are covered in separate appendices to this final report.

II. GENERAL DESCRIPTION OF THE MONITOR

The instrument is comprised of four basic modules,

1. Sampling probe
2. Sample analyzer
3. Pump station
4. Remote readout/control.

These are shown diagramatically in Figures 1 and 2 and photographically in Figures 7 and 8 .

The probe section is comprised of an S-type pitot tube, a nozzle for extracting a gaseous sample, and a tube to transport the sample for evaluation. In operation this unit is inserted into a laminar region of the stack. A sample is taken from the stack and drawn down the sample tube into the sample analyzer module using a high volume exhaust pump.

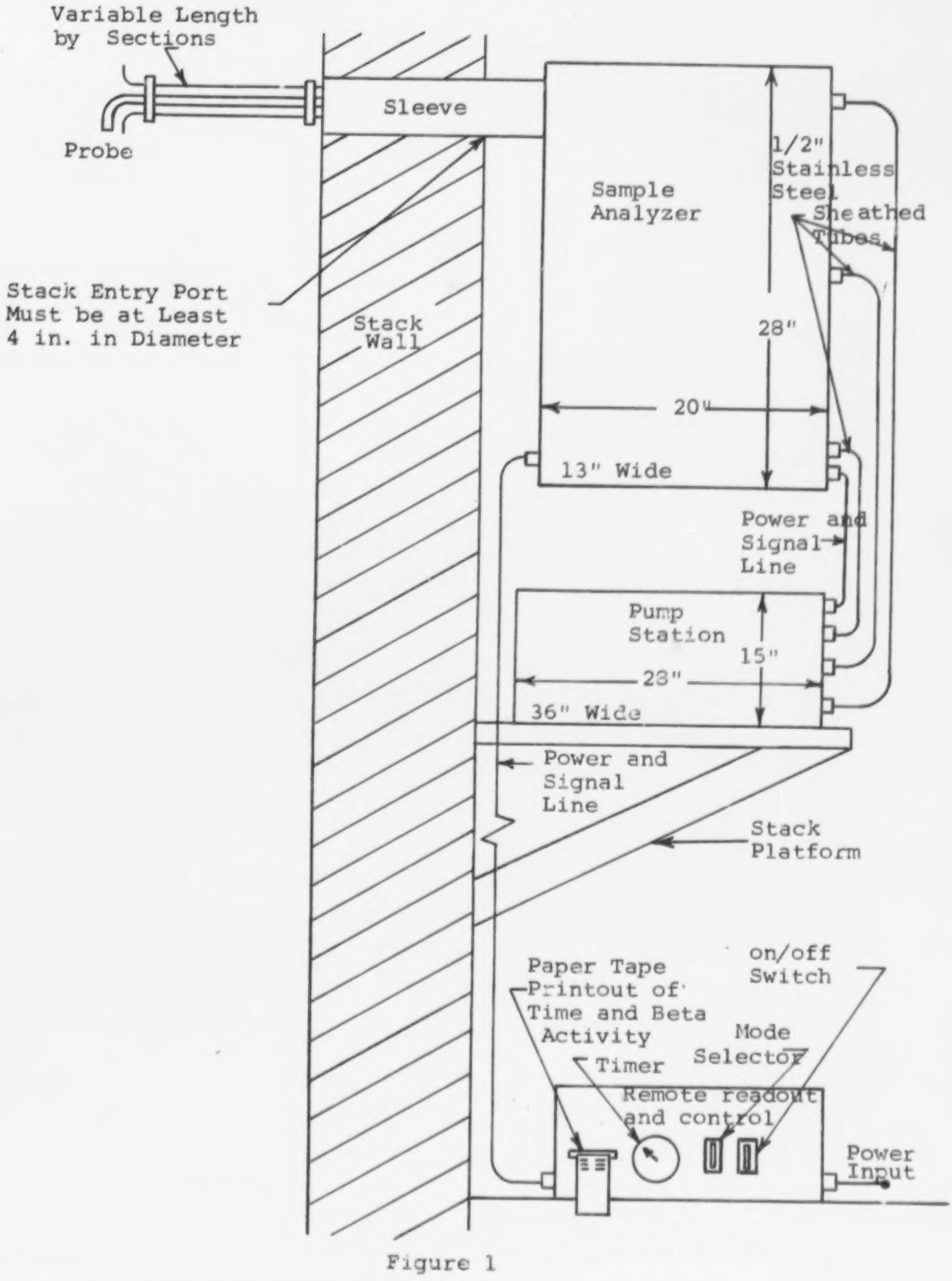

Variable Length
by Sections
Probe
Sleeve
Stack Entry Port
Must be at Least
4 in. in Diameter
Stack
Wall
Sample
Analyzer
1/2"
Stainless
Steel
Sheathed
Tubes
28"
20"
13" Wide
Power and
Signal
Line
Pump
Station
15"
23"
36" Wide
Power and
Signal
Line
Stack
Platform
Paper Tape
Printout of
Time and Beta
Activity
on/off
Switch
Mode
Selector
Timer
Remote readout
and control
Power
Input

Figure 1

STACK INSTALLATION OF THE FLY ASH MONITOR

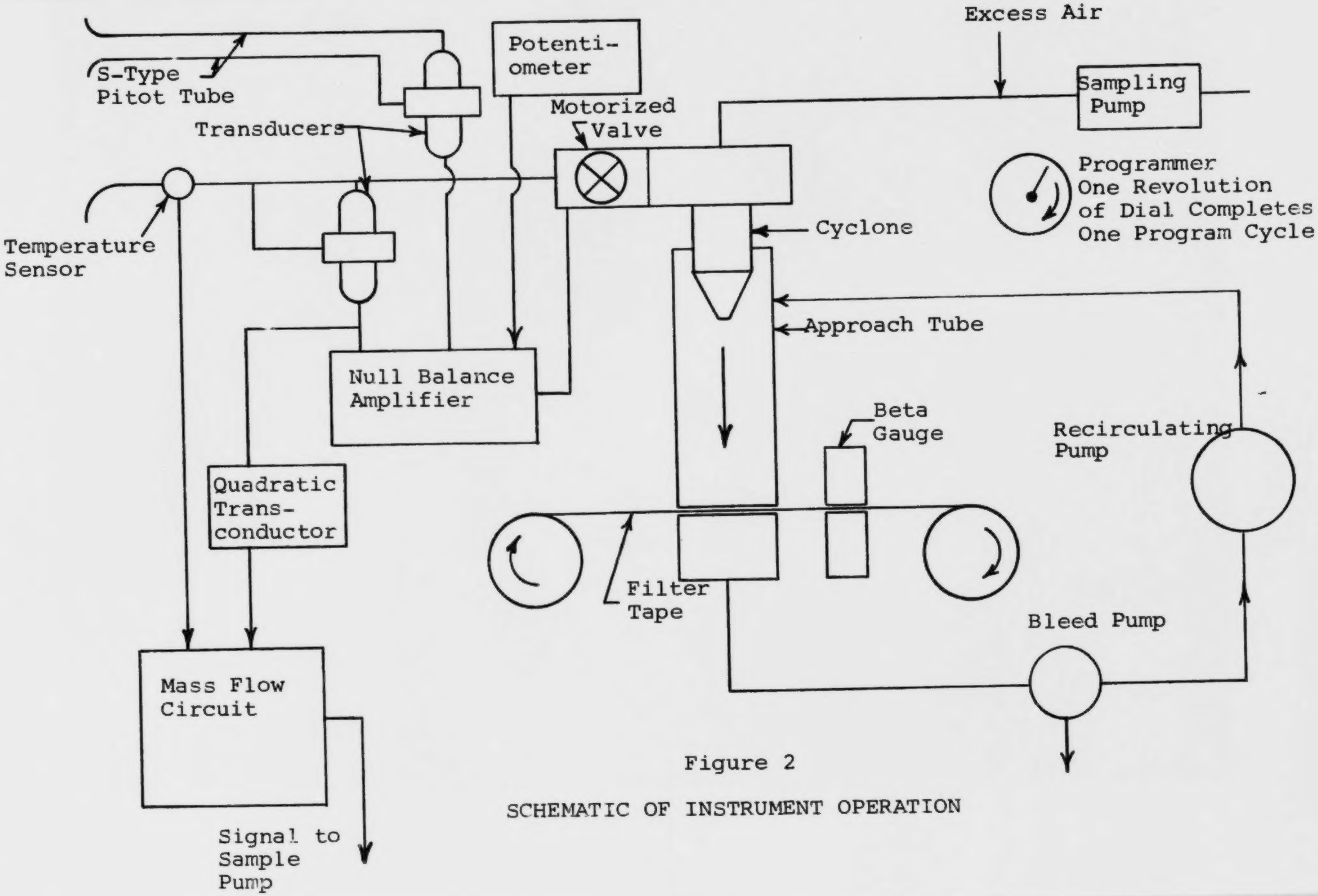

S-Type
Pitot Tube
Transducers
Temperature
Sensor
Potenti-
ometer
Motorized
Valve
Null Balance
Amplifier
Quadratic
Trans-
conductor
Mass Flow
Circuit
Signal to
Sample
Pump
Excess Air
Sampling
Pump
Programmer
One Revolution
of Dial Completes
One Program Cycle
Cyclone
Approach Tube
Beta
Gauge
Recirculating
Pump
Filter
Tape
Bleed Pump

Figure 2

SCHEMATIC OF INSTRUMENT OPERATION

The suspended fly ash is removed from the stream by a high efficiency cyclone which acts as a primary collector. The fly ash sample is then deposited on a filter paper tape for mass assessment using a beta gauge technique. Provisions are incorporated for sampling either at a fixed sample velocity, or an automatic isokinetic velocity. Selection of the sampling mode, control of the instrument and readout facilities are provided in the readout/control module. The remote readout/control module can be located up to 125 ft. away from the sampling and pump modules. This allows this unit to be conveniently situated, for example, at the base of the stack, or in a control room at any reasonable distance from the other units. The present limitation is at 125 ft. only because that is the length of the existing signal cable. In operation the sampling and pump station modules are located at the stack access port. The outside dimensions of the several modules are indicated on Figure 1.

The instrument is controlled from the remote unit. All power for the instrument is supplies to the remote module and distributed from there. The instrument is turned on and off and its operating mode is selected at the remote station. Three operating modes are available, (1) sampling at isokinetic velocity only, (2) fixed velocity only, or (3) both isokinetic and fixed velocity alternately.

The readout in the remote module prints out both the time at printout and the number of beta particles passing through the collected fly ash sample in the evaluation interval. This measure of beta activity is related by calibration to the mass of fly ash collected and thus this data characterizes the stack's emissions. To convert the measured sample mass to grains per cubic foot or pounds of fly ash per 1000 pounds of flue gas or any other expression it is also necessary to know the stack geometry, the gas flow conditions, the unattenuated level of beta activity and the preset mass of gas sampled. Since in normal operation the base level of beta activity, preset mass of gas, and the stack geometry will be constant, the attenuated beta activity readout can be directly converted to grains per standard cubic foot with the use of a simple graph.

III. MONITOR DESIGN AND OPERATION

The prototype monitor was designed to automatically sample and assess incinerator stack solid effluents. It was designed to sample at both an automatic isokinetic velocity and at a predetermined, constant or fixed velocity.

The instrument operation can best be described by reference to the schematic diagram, shown in Figure 2.

The operation of the monitor is programmed as a function of time. The monitor performs sequential functions at predetermined intervals. The program is visually displayed in the sampling module by a marker which turns through 360° for one complete cycle of the program, like a one-handed clock. The various sequential functions can be summarized by envisioning a clock face indicating the positions of the program. Starting the cycle from the commencement of the isokinetic sampling the monitor functions and related clock positions are as follows:

Approximate Elapsed Time From Start	Program Position Indicator	Function
0	9 o'clock	Start isokinetic sample
2	10.5	Tape advance, initiate beta count
5	11.3	Reset beta and mass flow counters
	11.7	Start fixed velocity sampling
7	1.5	Tape advance, initiate beta count
10	2.5	Back flush sample line and other lines
12	4.0	Stop back flush of sample line, continue with back flush of pitot lines
15	8.0	Reset beta and mass flow counters
16	8.3	Start interval clock count-down

The minimum time for one complete program is 16 minutes. The interval between cycles is selectable between 1 and 120 minutes and is determined by an interval timer. Setting the interval timer to its maximum of 120 minutes expands the period for one cycle to 136 minutes. That is, an isokinetic sample will be taken followed by a fixed velocity sample five minutes later. Approximately 126 minutes will elapse before the next isokinetic sample starts. In order to reduce the load on the monitor's pumps they may be automatically switched off during the interval between cycles. Thus, it is seen that the shortest period required to complete one program cycle is 16 minutes and the longest period during which one isokinetic and one fixed sample may be taken is 136 minutes.

Automatic sampling at the isokinetic velocity is accomplished by continuously comparing the gas velocity up the stack, measured with a Staushibe-type pitot tube, with the gas flow in the sampling line, as determined by measuring the pressure drop across a calibrated fixed length of the sampling line. The velocity at the inlet of the sampling probe is adjusted by means of a throttle valve to be identical with the velocity flowing up the stack.

The velocity comparison necessary to attain an isokinetic sampling condition is accomplished as follows. The differential pressure generated by the S-type pitot tube is monitored by a temperature compensated pressure transducer* in one leg of a differential amplifier. The transducer's voltage output is dependent upon the applied pressure differential.

The pressure differential generated in the calibrated section of the sampling line is monitored by a similar pressure transducer in the other leg of the differential amplifier. The amplifier is adjusted to be balanced under isokinetic flow conditions. Under non-isokinetic flow conditions the out-of-balance signal is used as an error signal in the differential amplifier controlling the in-line motorized variable throttle valve in the sense that the valve is driven to restore balance, i.e., isokinetic flow conditions.

---

*Statham Instruments, Inc., Model No. PM97TC ± 0.05 -350.

It is important to note that the pressure drops developed within the stack and sample tube are developed across different mechanical systems. It has been observed experimentally that under isokinetic conditions the pressure drops are not identical, although over a velocity range 20 to 50 fps they approximately follow the same pressure/velocity relationship. In order to off-set this difference, which is attributable to the mechanical systems, an electrical off-set or bias has been incorporated in the differential amplifier circuit.

The motorized valve (Figure 3) is integral with the primary separation cyclone and is constructed and operated as follows. The valve aperture is a leaf spring loaded to return to the fully open position. The position of the leaf is changed by driving a threaded shaft back and forth through ten revolutions. The maximum in-line travel of the threaded shaft is 3/8 inches. The valve opening is positioned to provide a tangential motion to the gas stream entering the cyclone. The leaf design adds to the tangential character of the gases entering the cyclone and ensures a near constant cyclone gas entry speed irrespective of the sampled gas velocity.

The cyclone was designed and tested to separate 99% by weight of fly ash when the flow conditions through the

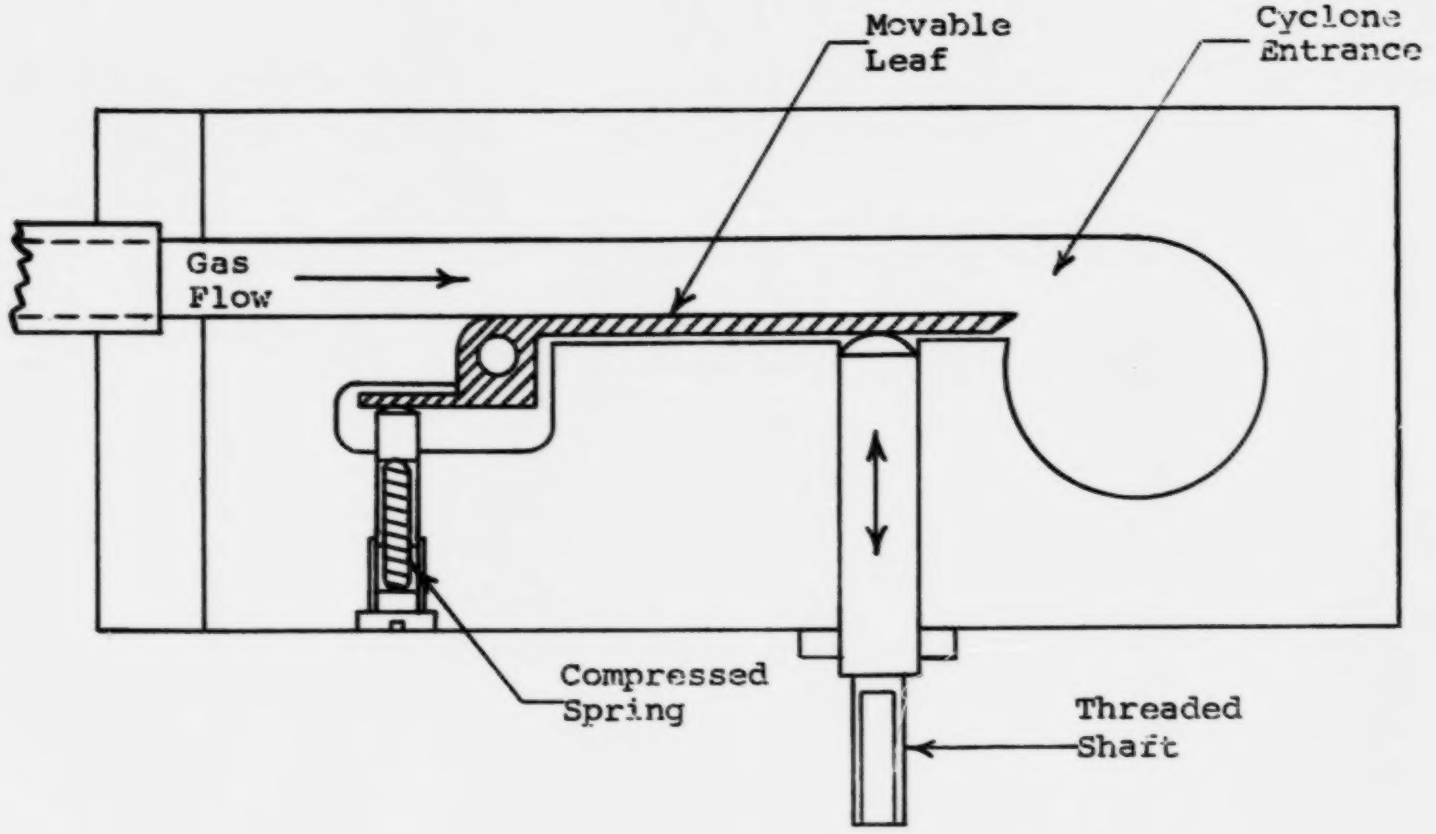

Movable
Leaf
Cyclone
Entrance
Gas
Flow
Compressed
Spring
Threaded
Shaft

Figure 3

MOTORIZED VALVE

cyclone were set to correspond to a stack velocity of 33 fps.

The leaf valve tending to make the inlet more tangential as the flow is decreased should aid in maintaining the efficiency over the operating range of 20-50 fps.

The sampled gas stream, stripped of its particulate matter leaves the gas outlet of the cyclone and is admixed with approximately 30 cfm of atmospheric air before passing through the high volume sampling pump. The added air serves to cool the gas stream and thus protect the pump from the effects of the high temperature stack gases.

The separated particulate matter leaves the dust outlet of the cyclone and enters the approach tube. This is part of the interlocking flow system which was designed to remove the fly ash sample from the base of the cyclone and deposit it uniformly on a filter paper tape in preparation for mass determination by beta particle attenuation.

The interlocking flow system is independent of the sample collection system. Thus the sampling kinetics are unaltered as the pressure drop across the filter paper is increased during sample deposition. The gas sampling system is left unaffected by the continuing particulate collection because the flow in the interlocking flow system is a recirculating loop through the filter paper which is independent of the mass sample flow, as shown in Figure 1. The centrifugal motion of the fly ash, given to it by the cyclonic action is broken up by 16 air jets of the recirculating air emitted from

1/8-inch diameter orifices located in the approach tube at approximately the level of the base of the cyclone. An air flow of approximately 3 cfm through this vented annulus effects a dispersal which results in a uniform deposition of fly ash. The dilution system is illustrated in Figure 4.

The interlocking flow system outlining the requisite flows is shown in Figure 5. The recirculating pump continuously recycles air across the filter paper. Although the flow rate of this recirculated air decreases as the pressure drop across the filter paper and deposit increases, this diminution of flow has no effect on the sampling velocity. To insure proper recirculation and a consequent net flow downward at all times, a small quantity of air, about 4 liters/min. is exhausted from the recirculation loop by the bleed pump.

When the monitor is not sampling, the main pump in the recirculation loop is used to backflush the sampling system. Appropriate solenoid valves are operated by the programmer and the lines are blown back with care being taken to protect the sensitive transducers. This is illustrated in Figure 6.

To prevent condensation, the probe, valve, and cyclone and approach system were traced with electrical heating elements. A total of approximately 1200 watts of external heat was applied. The probe and approach tube were wound with nichrome wire and covered with an insulating tape while a 2" X 4" strip heater* was installed on the bottom side of the valve block. These

---

*Minco Products, Inc., #HR6050-04A-8.24.

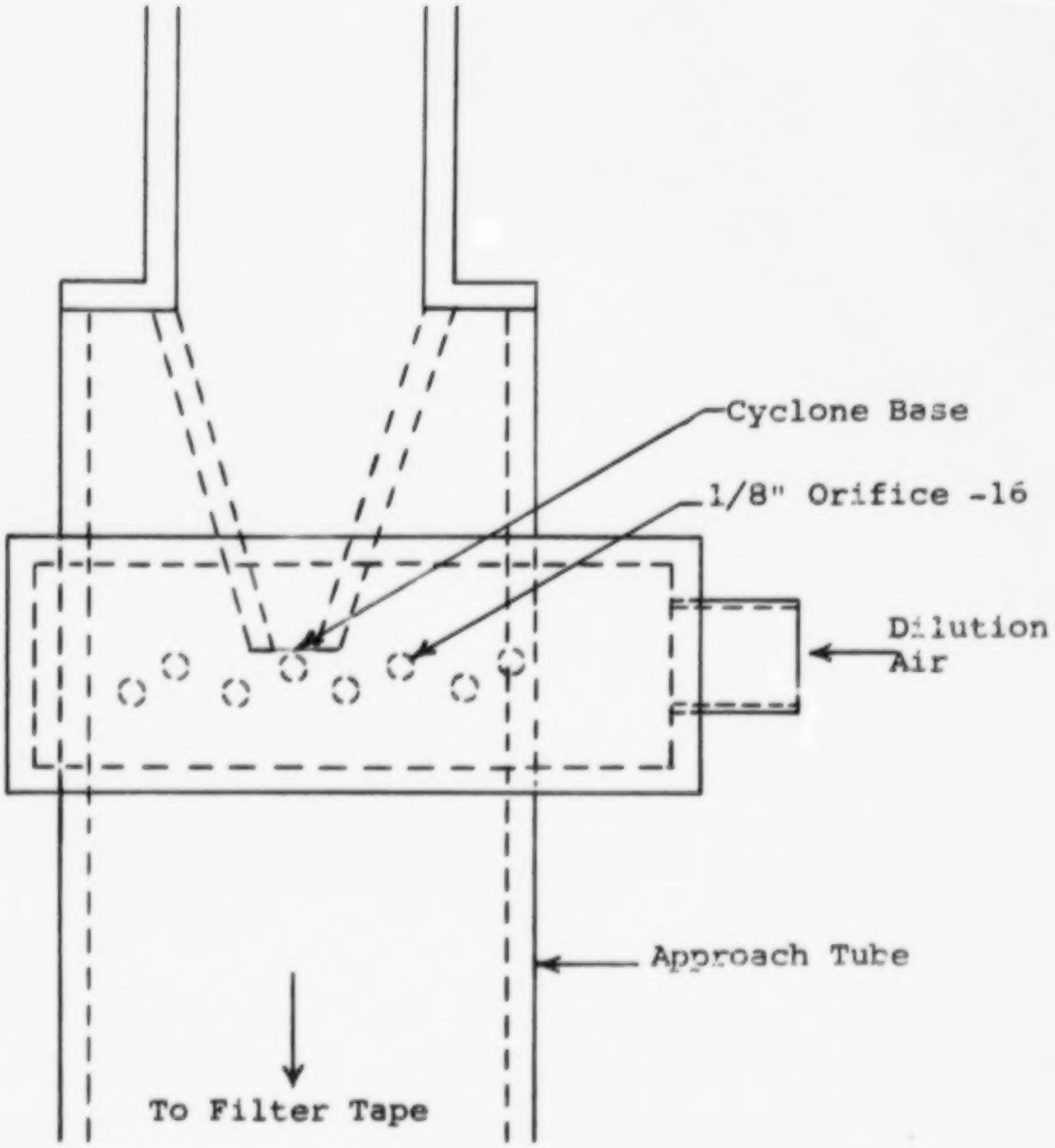
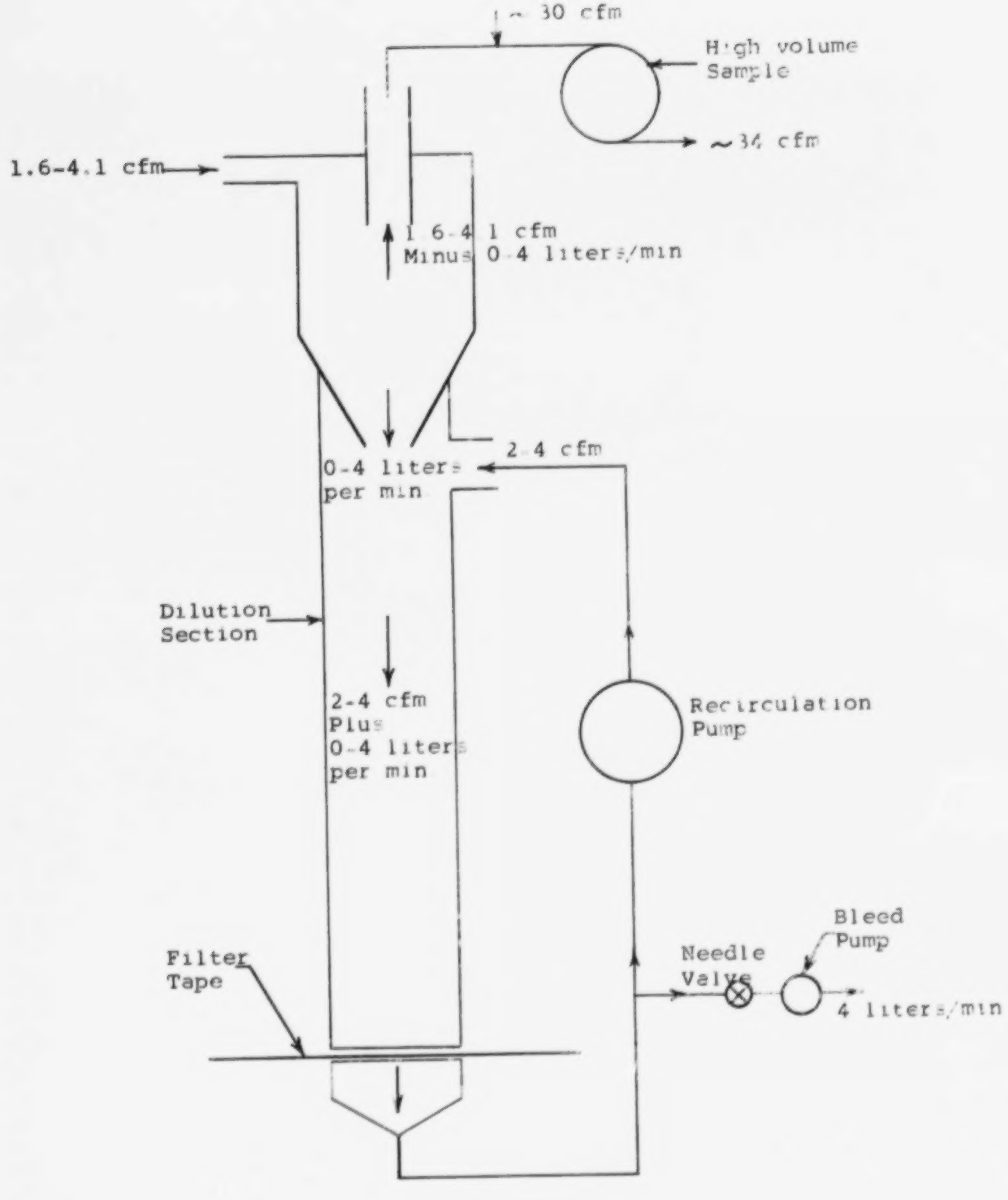

Cyclone Base
1/8" Orifice -16
Dilution Air
Approach Tube
To Filter Tape

Figure 4

DILUTION SYSTEM SECTION



~30 cfm
High volume Sample
~34 cfm
1.6-4.1 cfm
1.6-4.1 cfm Minus 0-4 liters/min
2-4 cfm
0-4 liters per min
Dilution Section
2-4 cfm Plus 0-4 liters per min
Recirculation Pump
Bleed Pump
Needle Valve
4 liters/min
Filter Tape

Figure 5

INTERLOCKING FLOW SYSTEM

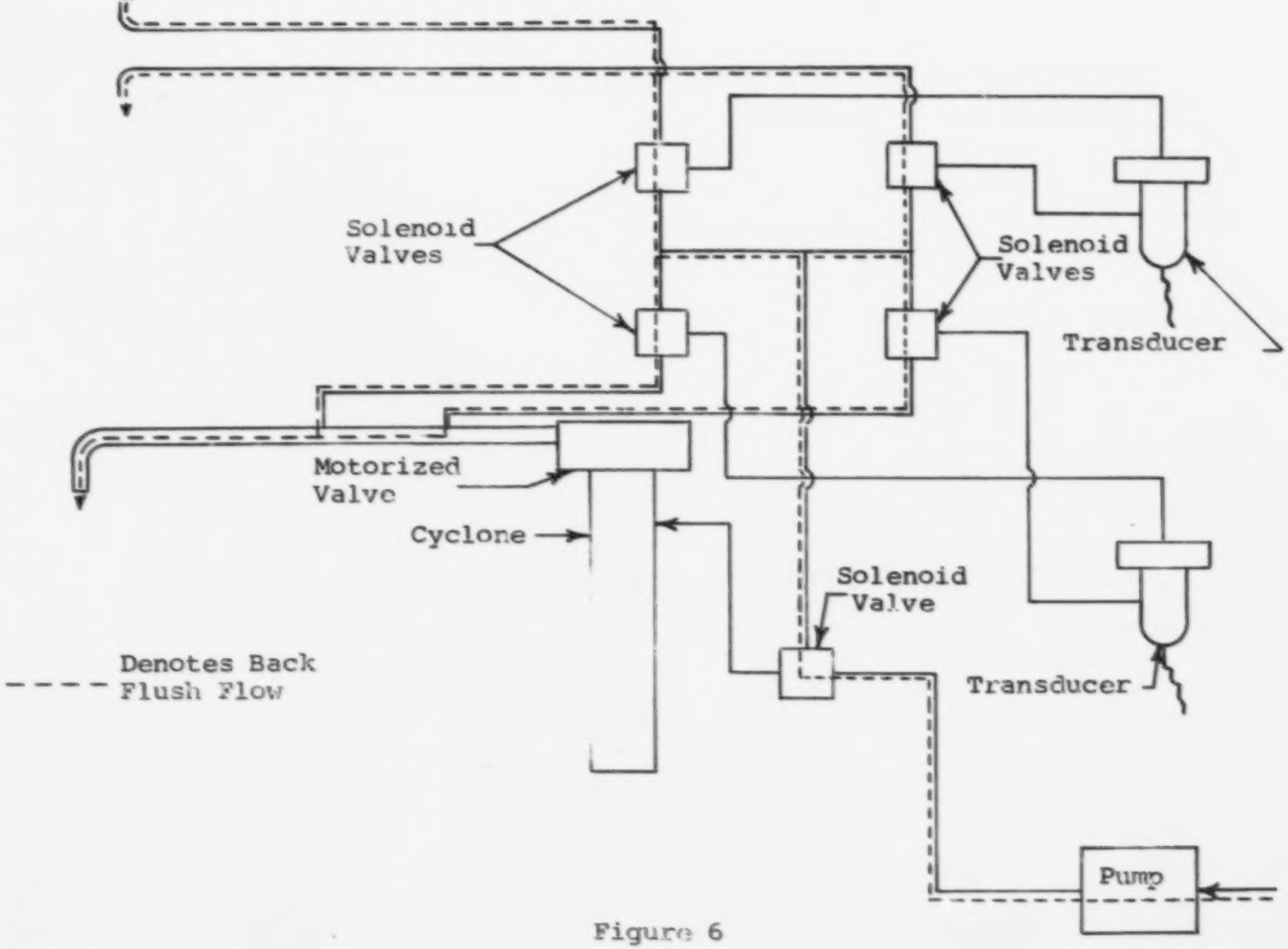

Solenoid Valves
Solenoid Valves
Transducer
Motorized Valve
Cyclone
Solenoid Valve
Transducer
Denotes Back Flush Flow
Pump

Figure 6

BACK FLUSH

measures have effectively precluded condensation which was otherwise experienced due to the high dew point of the stack gases.

After a preselected mass of the stack gas stream has been sampled, the sampling pump is automatically stopped and the filter tape with collected fly ash deposit is advanced about two inches to position it beneath a Promethium beta emitter. The number of beta particles transmitted through the filter paper and fly ash is observed for a precise preset time interval of 2'45". The beta count is related to the mass of fly ash on the filter paper using the relationship:

$$I/I_o = e^{-.134w}$$

where I_o = beta transmission through the filter substrate only,

I = beta transmission through the fly ash deposit and filter substrate,

w = mass of fly ash per unit area, mg/cm^2.

In addition to its function in isokinetic control, the pressure transducer monitoring the pressure drop across the sample line also provides a signal to determine the mass flow rate of the gas down the sample tube. The square root of the voltage developed by the transducer is proportional to the mass flow rate. This square root of voltage is converted to a current signal which is in turn converted to a frequency output through a unijunction transistor stage. The pulse train from the unijunction is counted on an electromechanical pulse counter. The pulse counter has a preset feature which emits a signal when the number of pulses has reached the preset number. The sampling period is thus terminated. The temperature correction necessary to insure a constant mass of gas is also taken into account in this system. A resistance-type thermal sensor is integrated into the system and acts to proportionally increase the volume of gas sampled with increasing temperature.

IV. FIELD TEST SITES

Three incinerators were used for on-site evaluations of the fly ash monitor. These were the Southwest Incinerator in Chicago, Illinois; the South Side Incinerator in Milwaukee, Wisconsin; and the Hamilton Avenue Incinerator in Brooklyn, New York. Data from Chicago is reported from April 29 to May 20 (Table 1-19), Milwaukee from May 21 to May 23 (Table 20-22), and New York from June 18 to June 22, 1968 (Table 23-27).

CHICAGO

The Chicago Southwest Incinerator Plant has a capacity of 1200 tons per day, in four 300 ton/day rotary kiln furnaces. The plant has two stacks, each stack servicing two furnaces. Each furnace is equipped with a wet bottom, large subsidence chamber, and a wet collector to effect some measure of particulate matter removal. Each furnace has a waste heat boiler associated with it for the production of steam from the incineration waste gases.

The two stacks are identical. Each is 250 ft. high with a platform and access ports into the stack at the mid-point. All testing was done at this 125 ft. level of the East stack, at which point the stack has an inside diameter of 15 ft. 4 inches. The instrument was positioned at the South access port. The total length of the probe was 10 ft., consisting of an initial section of 4 foot and two-3 foot extensions and was positioned so that the probe laid on a North-South radius of the stack, 65 inches from the inside wall. Independent testing was performed from the East access port and independent velocity and temperature measurements were made from both the West and East access ports. See Figure 7, 8, and 9.

MILWAUKEE

The South Side Incinerator in Milwaukee is a batch type incinerator. The plant has two 150 ton per day burning units connected to a common natural draft stack.

The incinerators are batch fed from hoppers located above the furnaces. Each unit consists of a furnace combustion chamber, bridgewall, baffles, and breeching. Auxiliary gas firing is available but rarely used.

The gases are partially cleaned by changes in gas velocity, and changes in gas direction to induce particulate settling, and impingement. However, the principal dust collecting device is an arrangement of wetted, staggered, tank-type baffles located in the breeching of each unit before the

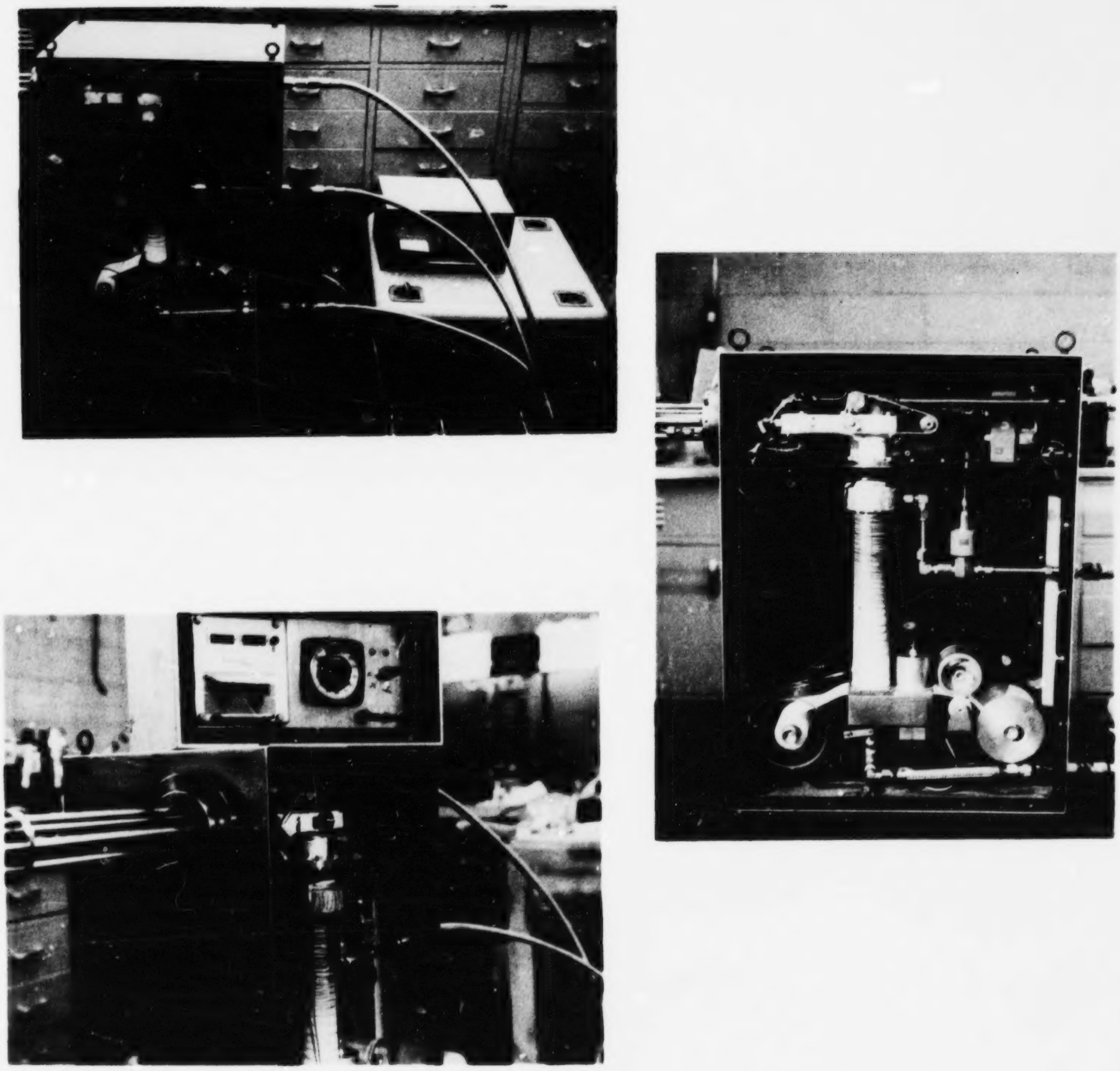


Figure 7
APWA FLY ASH MONITOR

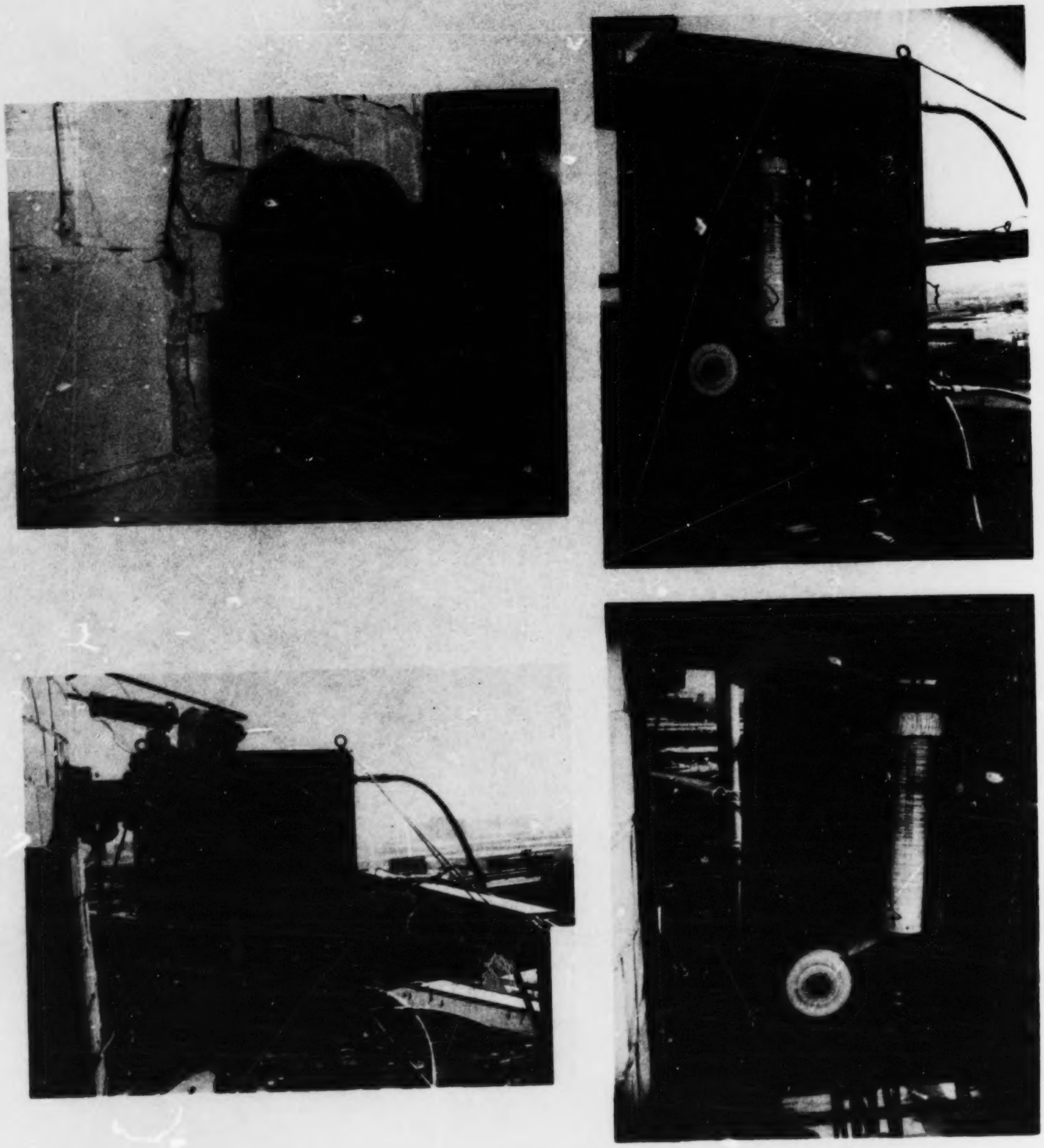


Figure 8
APWA FLY ASH MONITOR INSTALLED ON SOUTHWEST INCINERATOR, CHICAGO

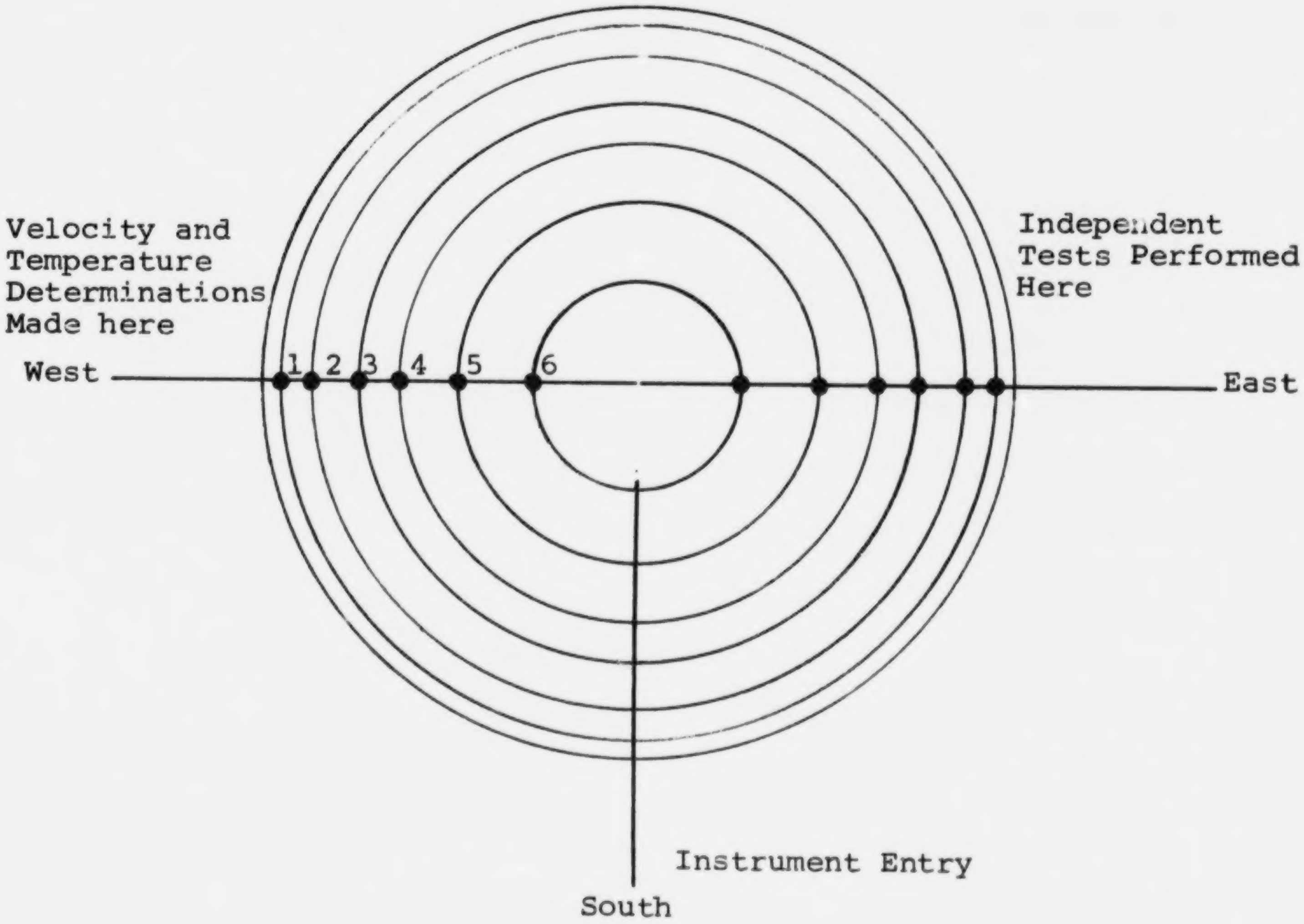

Velocity and Temperature Determinations Made here
Independent Tests Performed Here
West
East
1
2
3
4
5
6
Instrument Entry
South

Figure 9

PLAN VIEW OF SETUP AT
SOUTHWEST INCINERATOR, CHICAGO
SHOWING SIX EQUAL AREA SAMPLING ZONES

common chamber at the entrance to the stack. The tank-type baffle elements are continually wetted and dust is collected by impingement on these wetted surfaces. The dust collected is carried away in a water slurry to a clarifier from which the wetted fly ash is removed. The water is chemically treated and reused in the dust collection system.

The instrument was installed on a platform approximately 45 ft. above ground level. The probe of the instrument extended along a radius of the stack. The inlet nozzle of the instrument was 44 inches from the inside stack wall. During the period that the instrument was operating, the County of Milwaukee Department of Air Pollution Control under the direction of Mr. F. R. Rehm, performed independent mass emission tests using ASME PTC 27 - 1957 prescribed high volume sampling test procedures. The test positions of the Air Pollution Control Department were on two-90° radii on either side of the fly ash monitor.

BROOKLYN

The Hamilton Avenue Incinerator in Brooklyn is a continuous feed type with flat traveling grates. The plant has four furnaces serviced by two identical stacks.

No wet collection methods of trapping fly ash are used in this plant. Fly ash screens located near the end of the breeching area just before the stack opening are the only air cleaning device in use. The screens are used only to trap gross particulate emissions.

The fly ash monitor was installed about 60 ft. above grade on one of the two stacks in the plant.

V. RESULTS

The data obtained from field operation of the monitor at the three different locations are presented in Appendix A in a series of 27 tables. Each table represents a single day's operation. On each table is (1) a time, on a 24-hour clock, which is the time at completion of the beta evaluation. This is three minutes after gas sampling was complete; (2) the mode of the sample, whether the sample was taken at isokinetic or fixed velocity; and (3) the grain loading of the sample in grains per standard cubic foot of air. The standard cubic foot in this expression is room air at 60°F and 29.9" Hg. The flow meter was calibrated in the laboratory using air and no attempt has been made to calibrate the data for stack gas composition. The expression of grain loading based on air rather than stack gas is, of course, arbitrary but is wholly valid if the stack gas obeys the perfect gas law. Deviations from the perfect gas law are generally greatest as pressure increases and temperature decreases. Since the system was near atmospheric pressure and at a temperature of 500 or 600°F, i.e., well above the boiling point of water, perfect gas conditions were well approximated even for the water vapor.

The data are presented by day, with a greater or lesser number of samples being taken on any one particular day.

The daily isokinetic samples are averaged; the samples taken at a fixed velocity are averaged, and the average of all the daily samples are determined. A summary of all these averages are presented in Table 1 along with a record of the velocity of the fixed velocity sampling.

Several days of data are presented on graphs, Figures 10 to 14, which show the fluctuation of grain loading throughout the day. On some of these plots, some data points have been omitted for clarity.

The results of the tests conducted independently by MCDAPC are presented in Tables 1, 2, and 3 and Figure 15. The results of the manual isokinetic tests performed by IITRI in Chicago are presented in Tables 4 and 5 and Figure 16. These tests yield data which are independent of instrument operating characteristics, and have been used throughout this report, as a standard for evaluation of the instrument.

VI. DISCUSSION OF RESULTS

A. GENERAL DISCUSSION

A wide range of grain loading was found throughout the duration of the entire test program ranging from a low of .001 grains/SCF to a high of .286 grains/SCF which was observed in Chicago on May 7. The composite daily averages ranged from .030 to .132 grains/SCF.

In general the composite daily averages of samples obtained at isokinetic velocity and at fixed velocity are similar, being

Table 1

SUMMARY OF INSTRUMENT OPERATION
(Daily Averages)

Date	Average			Fixed Velocity, fps
	Iso	Fixed	Both	
Chicago Southwest Incinerator				
4/29	0.079	0.070	0.075	48
4/30	0.043	0.041	0.042	
5/1	0.061	0.066	0.064	
5/3	0.066	0.076	0.071	
5/6	0.079	0.078	0.079	36
5/7	0.068	0.065	0.067	
5/8	0.094	0.096	0.095	
5/9	0.044	0.050	0.047	48
5/10	0.067	0.071	0.069	
5/11	0.057	0.063	0.060	
5/12	0.077	0.072	0.075	
5/13	0.073	0.076	0.075	30
5/14	0.095	0.115	0.105	48
5/15	0.050	0.059	0.055	
5/16	0.051	0.034	0.043	46
5/17	0.030	0.043	0.037	
5/18	0.032	0.039	0.036	
5/19	0.034	0.041	0.038	
5/20	0.050	0.047	0.049	
Milwaukee South Side Incinerator				
5/21	0.039	0.044	0.042	46
5/22	0.090	0.085	0.088	
5/23	0.132	0.111	0.122	
Brooklyn Hamilton Avenue Incinerator				
6/18	0.058	0.055	0.057	43
6/19	0.058	0.064	0.061	
6/20	0.058	0.061	0.060	
6/21	0.055	0.062	0.059	
6/22	0.060	0.075	0.068	

Table 2

COMPARISON OF INSTRUMENT OPERATION
WITH INDEPENDENT TESTS OF THE MILWAUKEE COUNTY DEPARTMENT
OF AIR POLLUTION CONTROL (MCDAPC)

Grains/SCF			
Independent Tests		Instrument Tests	
Reported by MCDAPC	Converted to Inst. S. C.[(a)]	Reported	Reported X(1.5)
0.154	0.147	0.094	0.141
0.179	0.169	0.120	0.180
0.208	0.197	0.128	0.192

(a) Instrument Standard Conditions, 29.9"Hg. 60°F

Table 3

COMPARISON OF INSTRUMENT OPERATION AND INDEPENDENT TESTS OF MCDAPC IN MILWAUKEE

Independent Tests				Instrument Operation				
Date	Time	Grains/SCF[a]	Grains/SCF[b]	Grains/SCF (Average)	Grains/SCF	Test No.	Time	Type of Sample
5/22	1225 to 1413	.154	.147	.094	.106	897	1246	I
					.073	898	1251	F
					.077	899	1304	I
					.097	900	1309	F
					.088	901	1322	I
					.092	902	1327	F
					.075	903	1340	I
					.080	904	1346	F
					.112	905	1358	I
					.144	906	1404	F
5/22	1456 to 1636	.179	.169	.120	.136	911	1453	I
					.077	912	1458	F
					.139	913	1511	I
					.146	914	1516	F
					.131	915	1529	I
					.081	916	1534	F
					.117	917	1547	I
					.106	918	1552	F
					.137	919	1605	I
					.124	920	1611	F
					.110	921	1623	I
					.114	922	1629	F
					.162	923	1641	I
					.106	924	1647	F
5/23	0926 to 1120	.207	.197	.128	.119	971	0921	I
					.103	972	0926	F
					.109	973	0943	I
					.082	974	0947	F
					.112	975	0958	I
					.133	976	1003	F
					.155	977	1015	I
					.140	978	1020	F
					.183	979	1033	I
					.140	980	1038	F

[a] 29.92 in. Hg, 32°F

[b] Converted to instrument operation datum, 29.9 in. Hg, 60°F.

Table 4

COMPARISON WITH CERAMIC THIMBLE GRAIN LOADING TESTS IN CHICAGO

				Instrument		
Date	Time	Stack Position	Grains per scf	Grains per scf	Time	Type of Sample
5/ 8	1335-1345	Pt. 6	0.206	0.099	1339	I
				.104	1344	F
5/ 9	1441-1459	Traverse	.181	.045	1500	I
				.033	1505	F
5/ 9	1528-1542	Traverse	.149	.050	1535	I
				.018	1540	
5/10	1447-1452	Pt. 6	0.248	.069	1445	F
				.034	1457	I
				0.059	1503	F

Table 5

COMPARISON WITH GLASS FIBER FILTER TESTS AT STACK POINT 6 IN CHICAGO

				Instrument		
Test No.	Date	Time	Grains per scf	Grains per scf	Time	Type of Sample
1	5/10	1514	0.0184	0.039	1516	I
2		1523	.0223	.061	1521	F
3		1535	.0186	.095	1534	I
4	5/17	950	.0185	.028	949	F
5		955	.0321			
6		1000	.0350			
7		1005	.0430			
8		1010	.0530			
9		1016	.0520			
10		1020	.1127			
11		1024	.0548			
12		1028	.0487	.049	1031	I
13		1043	.0496	.036	1037	F
14		1049	.0458	.041	1049	I
15		1053	.0358	.055	1055	F
16		1102	.0319			
17		1108	.0386	.015	1108	I
18		1113	.0311	.033	1113	F
19		1117	.0273			
20		1121	.0275			
21		1125	0.0381	.038	1126	I
				0.045	1131	F

DATA FROM TABLE 2 - APRIL 30, 1968

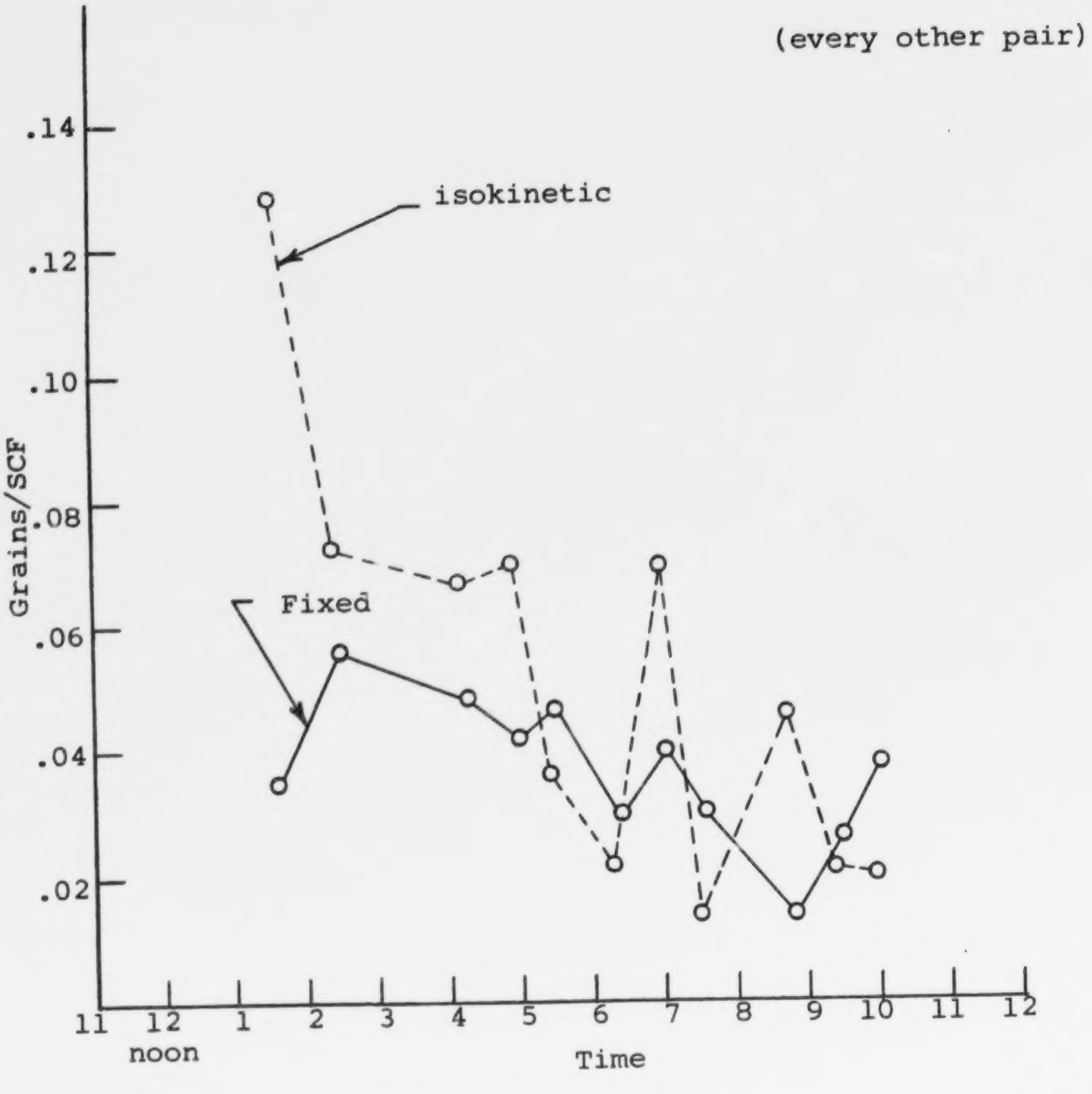


Figure 10
INSTRUMENT OPERATION

Data from Table 5, May 6, 1968

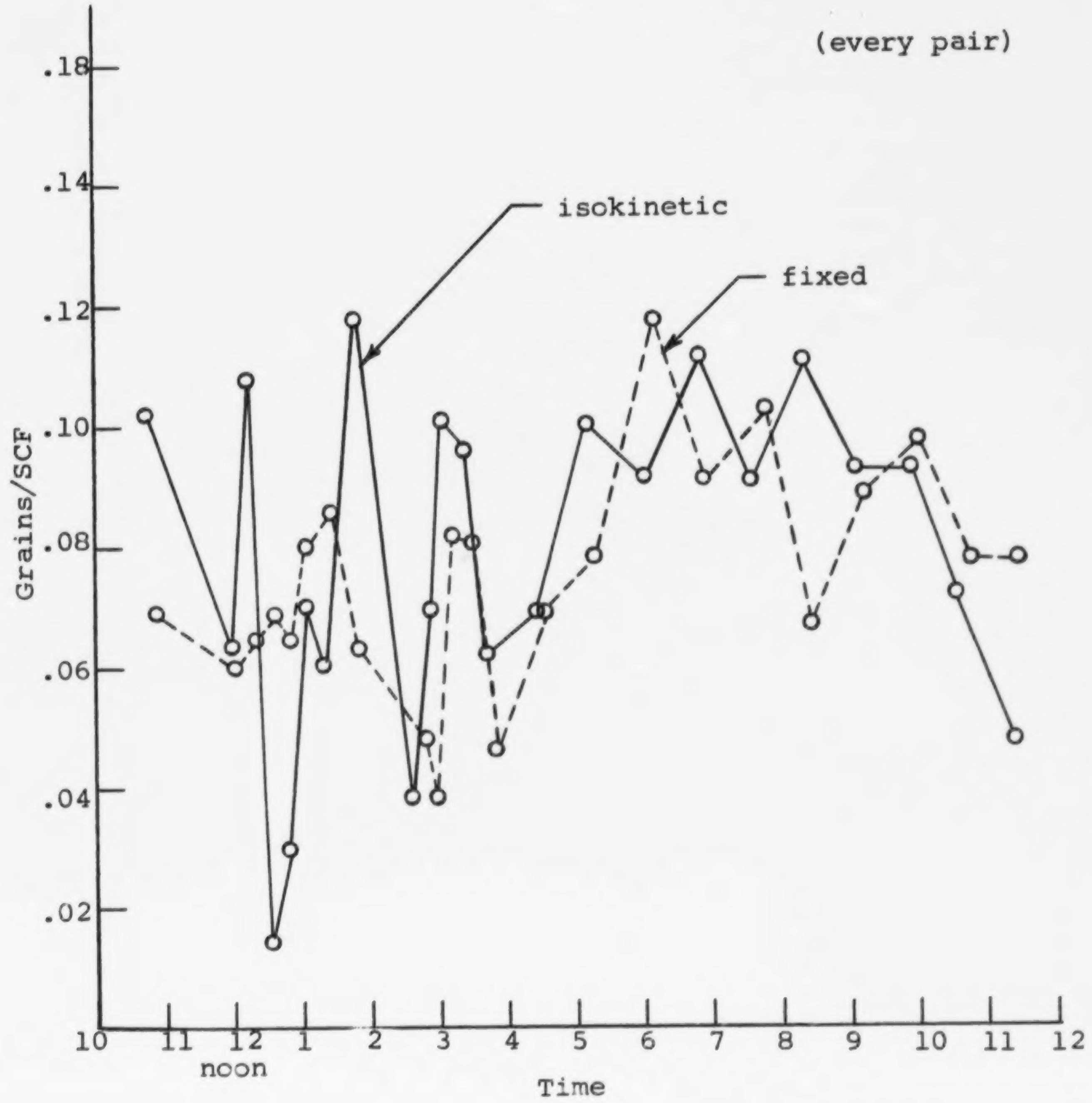
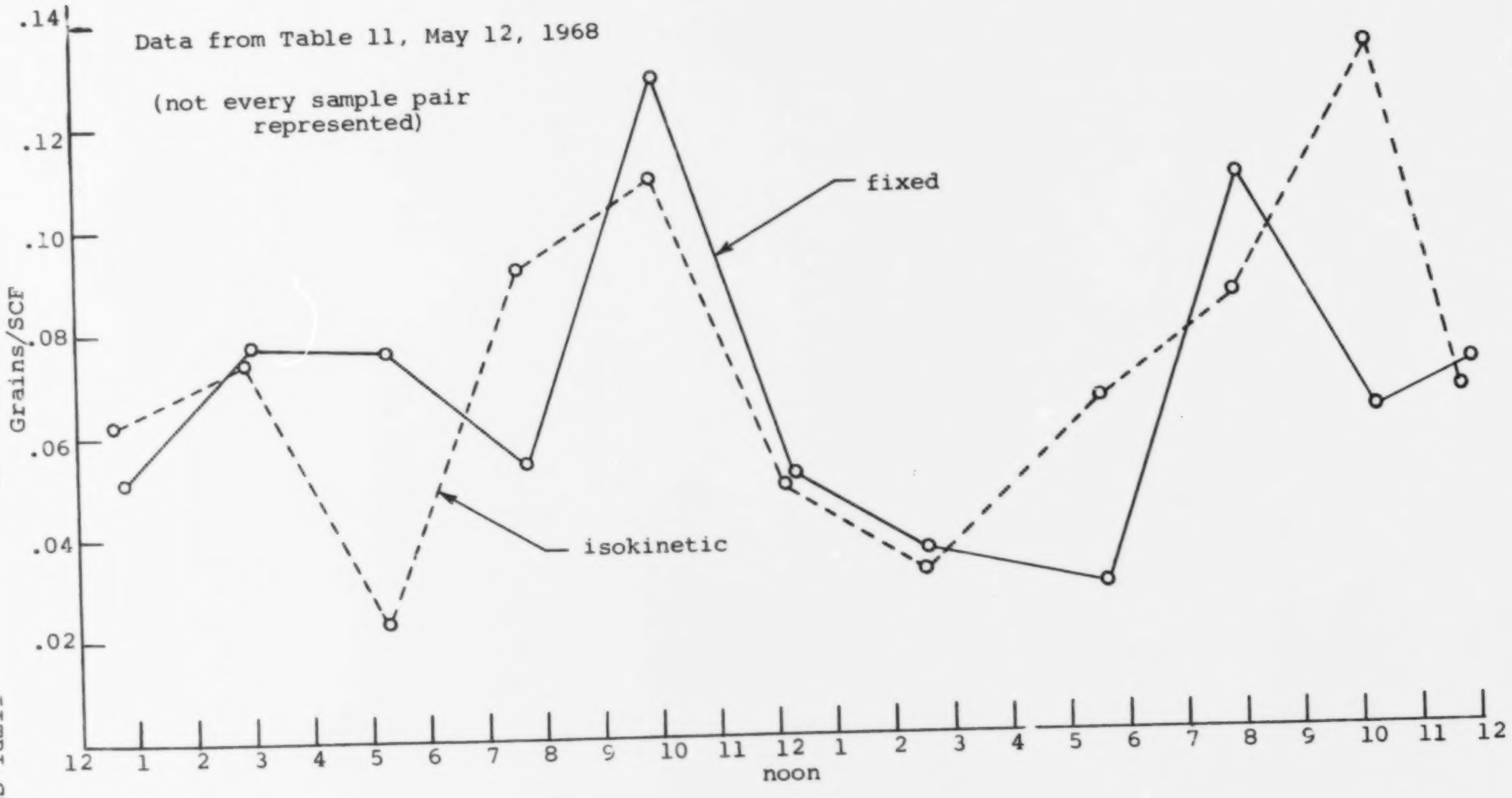


Figure 11
INSTRUMENT OPERATION



Data from Table 11, May 12, 1968

(not every sample pair represented)

Figure 12

INSTRUMENT OPERATION

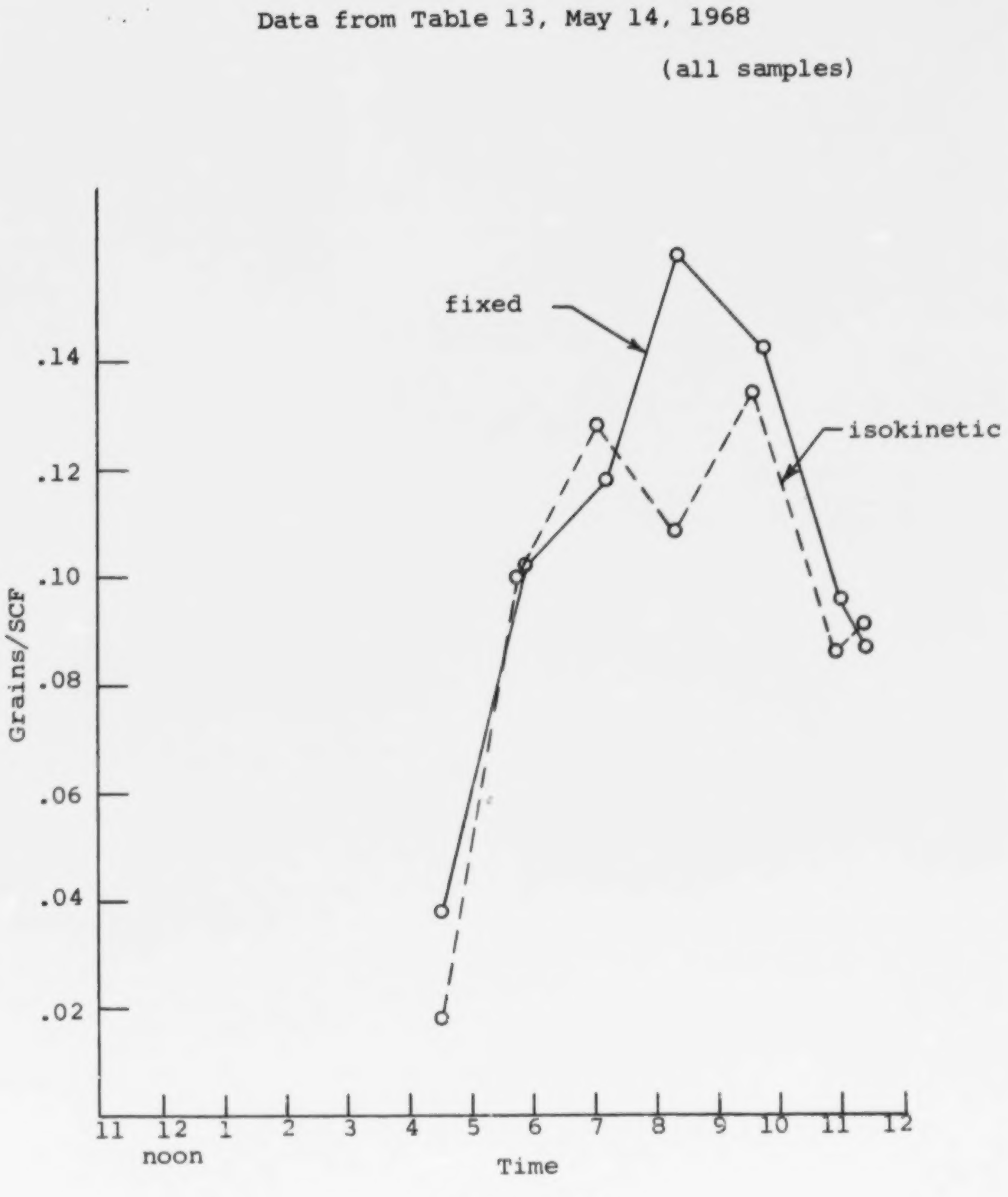


Figure 13
INSTRUMENT OPERATION

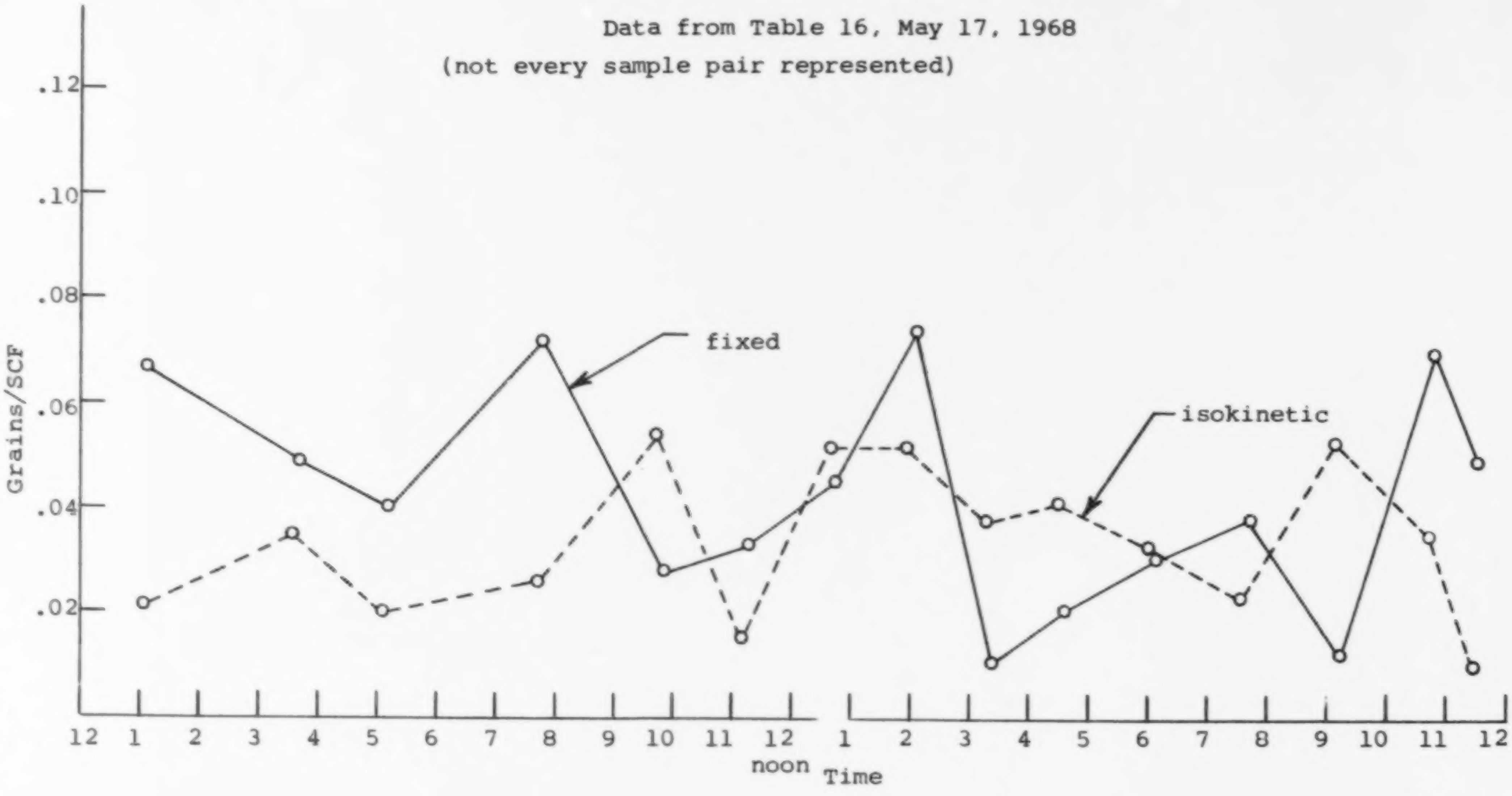

Data from Table 16, May 17, 1968
(not every sample pair represented)

Figure 14
INSTRUMENT OPERATION

on average within 5%. However, a maximum of 30% difference in these two averages was observed on May 16 in Chicago.

The most concise summary of the entire field experience can be made by looking at the average of all the runs at each site. The composite averages of the three sites are:

Chicago (rotary kiln)	.062	Grains/SCF
Milwaukee (batch)	.085	Grains/SCF
Brooklyn (traveling grate)	.061	Grains/SCF

These averages cannot be viewed as characterizing the various incinerator emissions by type, since factors such as character of refuse burned and operation rates, about which no extensive data are available, have a profound influence on the character of the incinerator effluents. Consequently, it can be considered fortuitous that the three averages are in a relatively narrow range. It should be noted that while the data collected in Chicago was copious, (19 days), the New York operation extended over only five days and the data collected in Milwaukee was for three days. Further, during these three days, the average emissions for each day were widely different being .042, .088, and .122 grains/SCF respectively.

A principal objective of this study program was to determine whether or not there was a significant difference in the mass of samples collected under automatic isokinetic and fixed velocity conditions. The necessity of isokinetic sampling of various stack effluents has been in question and on the basis of the published work it was uncertain if isokinetic sampling was needed to obtain valid stack grain loading information for municipal incinerators.

To ascertain if there was a significant difference between the two sampling techniques based on the reported field data here, a statistical test of significance was applied to the data of two days selected at random from the total of 27 days. An independent "t" test was performed on the data for April 30 and May 11. The results of the "t" test indicated that for the data of April 30, the hypothesis that isokinetic and fixed velocity sampling were alike was correct to a 66% confidence level. For May 11 the confidence level was 72%. Thus there is a 66% or greater probability that isokinetic and non-isokinetic sampling techniques yield the same results of stack dust loading under the conditions reported.

The similarity may be real, i.e., independent of operating conditions, or it may be that the fly ash size distribution and/or isokinetic and non-isokinetic sampling velocities were similar enough for the tests to be essentially the same in both isokinetic and non-isokinetic sampling.

Considering particle size distribution, no measurements were made during the period of these tests. Published data for particle size distributions of emitted fly ash from an incinerator very similar to the Hamilton Avenue plant shows 39% by weight of the effluent to be below 15 microns in size[1], 17.8% to be below 10 microns, and 12% to be below 5 microns. Other published data for other plants show a range of 23% to 38% of the emitted fly ash to be under 10 microns in size[2], and 58% to be below 20 microns[3]. These fly ash distributions indicate that only a minor percentage by weight of fly ash is below the size, i.e., approximately 10 μ, where serious sampling errors would be expected under non-isokinetic conditions. However, the experimental results presented here indicate that non-isokinetic sampling is adequate for the evaluated emissions even through 60 to 80% of the particles were probably larger than 10 microns.

Concerning the similarity of sampling velocities, the fixed velocity was selected within the range of 30 to 48 fps and remained invariant throughout the duration of a comparison test with automatic isokinetic velocity sampling as shown in Table 1. During this same period of incinerator operation the automatic isokinetic sampling velocity could vary between approximately 20 to 50 fps and would thus be similar or identical with the fixed velocity for indeterminate periods of time. These data suggest, therefore, that under the field test conditions there is a mathematically significant similarity between the samples collected automatically isokinetically and non-isokinetically.

---

[1] APWA, Municipal Refuse Disposal, 1966, p. 192.

[2] Walker, A. B., Incineration of Solid Wastes, Symposium of Metropolitan Engineers Council on Air Resources, 1967, p. 78.

[3] Walker, A. B., "Electrostatic Fly Ash Precipitation for Municipal Incinerators - A Pilot Plant Study," Proceedings of 1964 National Incinerator Conference, May, 1964.

Thus the classification as similar of the automatically isokinetic and non-isokinetic samples is justifiable only as limited by the above qualifications. The conclusion to be drawn here is that a sampling velocity which is automatically and continuously isokinetic may not be necessary while an average isokinetic sampling velocity may be sufficient.

When looking at the sequential sampling results on a daily basis as shown in Figures 10 to 14 , the general trend can be noted. The samples generally trend in pairs, the adjacent isokinetic and fixed velocity samples are more similar than non-adjacent samples. This shows that stack conditions change greatly but relatively slowly and both sampling methods follow the changes. Also noted is the fact that there is no tendency for either sampling method to consistantly give higher grain loadings. The composite daily average for fixed velocity sampling is higher for 17 days and the isokinetic sampling results were higher for 10 days out of the total field test span of 27 days.

B. MILWAUKEE TESTS

In comparing the results of the independent dust loading tests with instrument operation in Milwaukee, transposition to instrument standard conditions must first be made. That is, the volume of gas at Milwaukee County Department of Air Pollution Control (MCDAPC) standard conditions must be converted to gas volume at instrument standard conditions before grain loading recomputation can be made. With the Milwaukee independent test data converted to the same base as the instrument, the test results are compared in Table 2.

The instrument grain loading results used for comparison with the independent tests conducted by MCDAPC were obtained by (1) taking the average of all 10 measurements (both isokinetic and fixed) obtained during the period of the first independent test, (2) taking the average of all 14 measurements obtained during the period of the second test, and (3) taking the average of all 10 measurements obtained during the period of the third test. These data are shown in Table 3.

Each of the grain loading determinations made by the independent tests is approximately 150% of the grain loading found by the instrument. Taking the results of instrument operation and multiplying by a factor of 1.5 leads to very similar results by both methods as shown below and in Table 2. The instrument and independent tests are then within ± 6% of each other.

Independent Tests	Instrument Tests X (1.5)
.147	.141
.169	.180
.197	.192

Figure 15 shows that the different values for both the independent manual isokinetic tests and the instrument averages

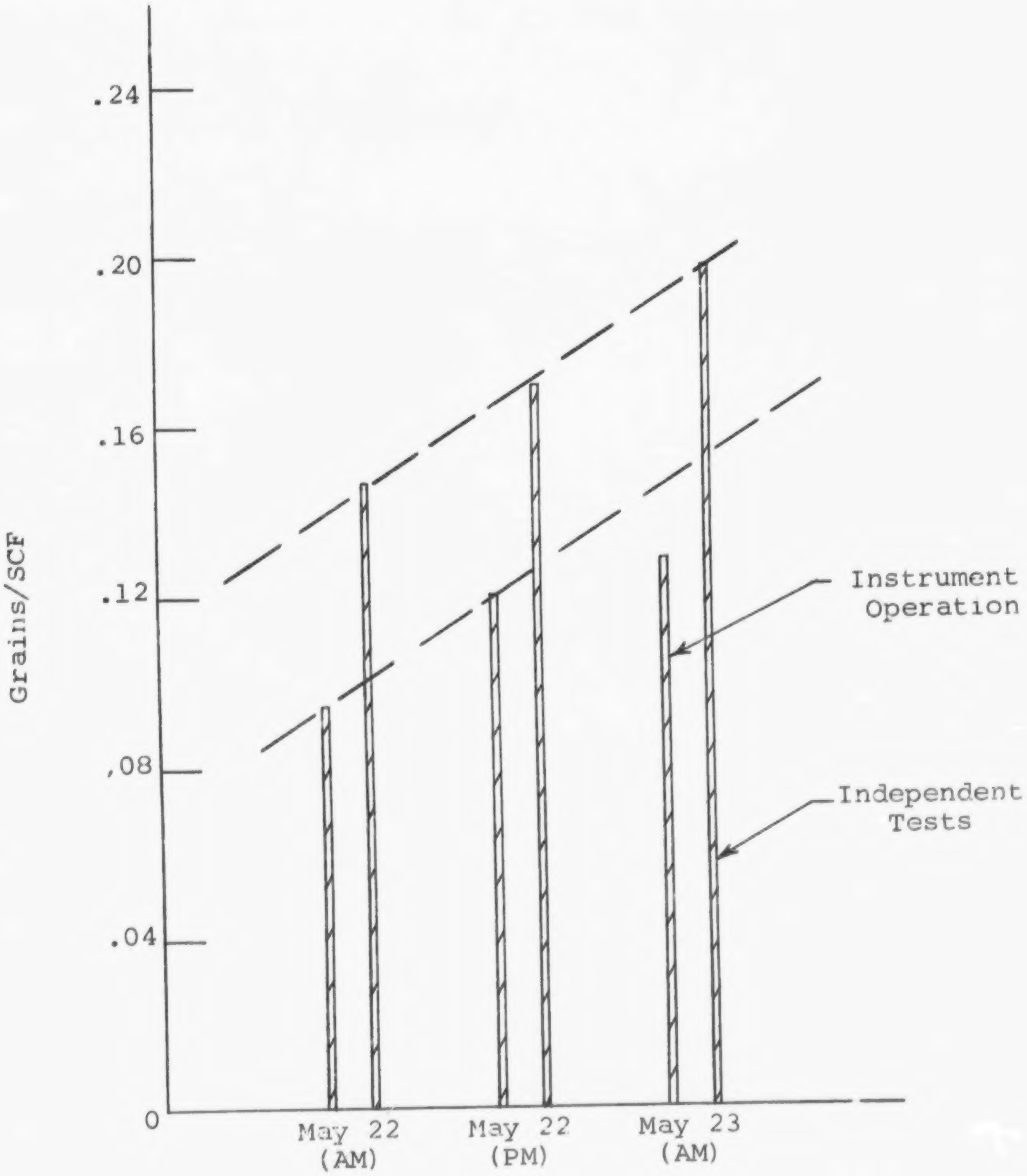


Figure 15

COMPARISON OF INDEPENDENT TESTS
IN MILWAUKEE
WITH INSTRUMENT OPERATION

both trend upward at the same rate. This consistancy of the two types of testing is indicated by the two parrallel lines drawn on the graph.

Because the MCDAPC tests were performed in accordance with the procedures prescribed by ASME PTC 127 - 1957, by experienced personnel, they are accepted as a standard by which the instrument can be compared. The independent tests were large sample volume tests as compared to instrument operation. The volume of stack gas assessed in the independent tests was of the order of 400 standard cubic feet per test while instrument samples were only about 3 standard cubic feet each.

The disparity between the instrument and independent tests is a systematic difference which may be ascribed to one or a combination of the following: (1) a systematic error developed in the beta gauge evaluation, (2) instrument sampling resulting in a systematic exclusion of either sample fines or large particles, (3) instrument sampling resulting in systematic exclusion of relatively very large particulate, macroscopic particles of the order of 1/4-inch diameter, (4) the instrument not sampling at those times of heavy dust loading following furnace charging, (5) line transport loss of the particulate sample because of deposition in the probe, valve, and cyclone, and (6) a systematic difference between single point and traverse sampling, that is, if the average stack loading as determined by a traverse over two radii examines a dust profile which is different than the loading at the single point of instrument insertion.

The beta evaluation system was recalibrated after the tests in New York and found to confirm the original calibration. Thus no errors were introduced from this possible source.

Previous experience with the cyclone collector showed a collection efficiency with the lowest flowrate, i.e., the worst possible operating condition, to be in excess of 95% with a 5-μ-mean diameter test dust. Observation during the field tests of the filter depositions and the after-cyclone line confirmed that no appreciable amount of material, coarse or fine, passed through the cyclone in normal monitor operation.

Very large particles, however, such as incompletely burned paper and other organic matter or chips of metallic or other non-combustible materials could have been excluded. Particles of the order of 1/4 to 3/8-inch diameter were observed in the independent tests conducted by MCDAPC. Although these flake-type particles, were few in number, they could represent a significant portion of the total mass of the particulate sample. These macroscopic flake-type particles could more easily be precluded from the monitor sample than could most other particles, because of the relatively small size of the instrument's sampling nozzle. The nozzle orifice is 1/2-inch in diameter while the nozzle used in the MCDAPC tests was 1 1/4 inch in diameter. With the one-half-inch nozzle there is less probability of collecting the large flakes.

If the dust burden is higher during or immediately after batch charging and if the instrument sampled the stack stream only during intervals when the furnaces were not being charged, an error in overall results indicating a lesser burden could be expected. During the short periods of charging, the emissions from the incineration process should be relatively severe because the charge of cold, wet material tends to momentarily quench the incineration and send the products of incomplete combustion up the stack. The record of furnace charging times compiled by MCDAPC indicates that the frequency of charging was greater than that of sampling, this supports the view that the monitor sampling was representative as regards charging times.

The error caused by loss of sample due to deposition in the probe, valve, and cyclone - those areas before the filter paper - is thought to be a very probable explanation of the difference noted between the independent tests performed by MCDAPC and instrument operation. At various times throughout the field experience the probe and other sections anterior to the filter depostion were inspected and cleaned. Invariably some amount of fly ash build-up was noted on these components. These sections were cleaned both before and after the Milwaukee field tests. There was, of course, no way to quantify and ascribe the spurious deposition to the 132 samples taken in Milwaukee. In the three independent tests performed by MCDAPC a large portion of their total sample collection was shown to be flushed from their sampling train. Tests number 2 and 3 had approximately 40% of the total collection accounted for by the material which was flushed from the sampling trains while test number one had a much higher percent (94%) accounted for by flushing. By analogy, conceding the 94% to be anomalous, it can be seen that line deposition can easily account for the consistent 50% difference between the independent tests and instrument operation. With a 40% possible line loss shown in the sampling train which had a larger diameter probe and less tortuous transport path than did the instrument, a 50% loss with the instrument sample can readily be visualized.

The remaining possibility which may account for part or all of the disparity is that the systematic difference is due to the difference between traverse and single point sampling. Assuming a steady state dust profile throughout the period of testing, the disparity could be due to the instrument reading only one point on the profile compared to an integrated sample collected during traverse. Making this assumption of a steady state dust profile, the monitor results could reflect the average stack dust loading by applying some empirical factor.

However, on the basis of the complex, changing flow observed throughout the incinerator system, this assumption of constant dust profile cannot be made.

C. CHICAGO TESTS

Independent tests were also performed by IITRI when the instrument was located at the Southwest Incinerator in Chicago. The independent tests in Chicago differed from the Milwaukee independent tests in type and duration of the individual tests. The test duration in Chicago was minutes compared to the hours-long runs in Milwaukee. That is, the Chicago independent tests sampled a relatively small volume of stack gas while the Milwaukee tests were large volume tests.

Two different types of independent tests were performed in Chicago. One type used a ceramic cartridge as the filter media and sampled about 20 standard cubic feet of stack gas. The second type of test used a glass fiber filter as the collector and passed a volume of about 6 standard cubic feet through the filter. In both cases the filter elements were located within the stack about 4 to 6 inches from the intake nozzle thus eliminating sample line deposition.

The correspondence between the glass fiber filter tests and instrument operation is generally quite good. These results are shown in Table 4. For filter tests 12 through 21 , the correspondence is extremely close. These data are plotted on Figure 16.

Both for traverse and single point tests the ceramic cartridge tests, however, do not compare favorably with instrument operation data as shown in Table 5. The ceramic thimble tests indicated a greater stack dust loading than did the instrument and the glass fiber filter tests. This anomoly, while not detracting from the validity of the test data, requires confirmation before elucidation.

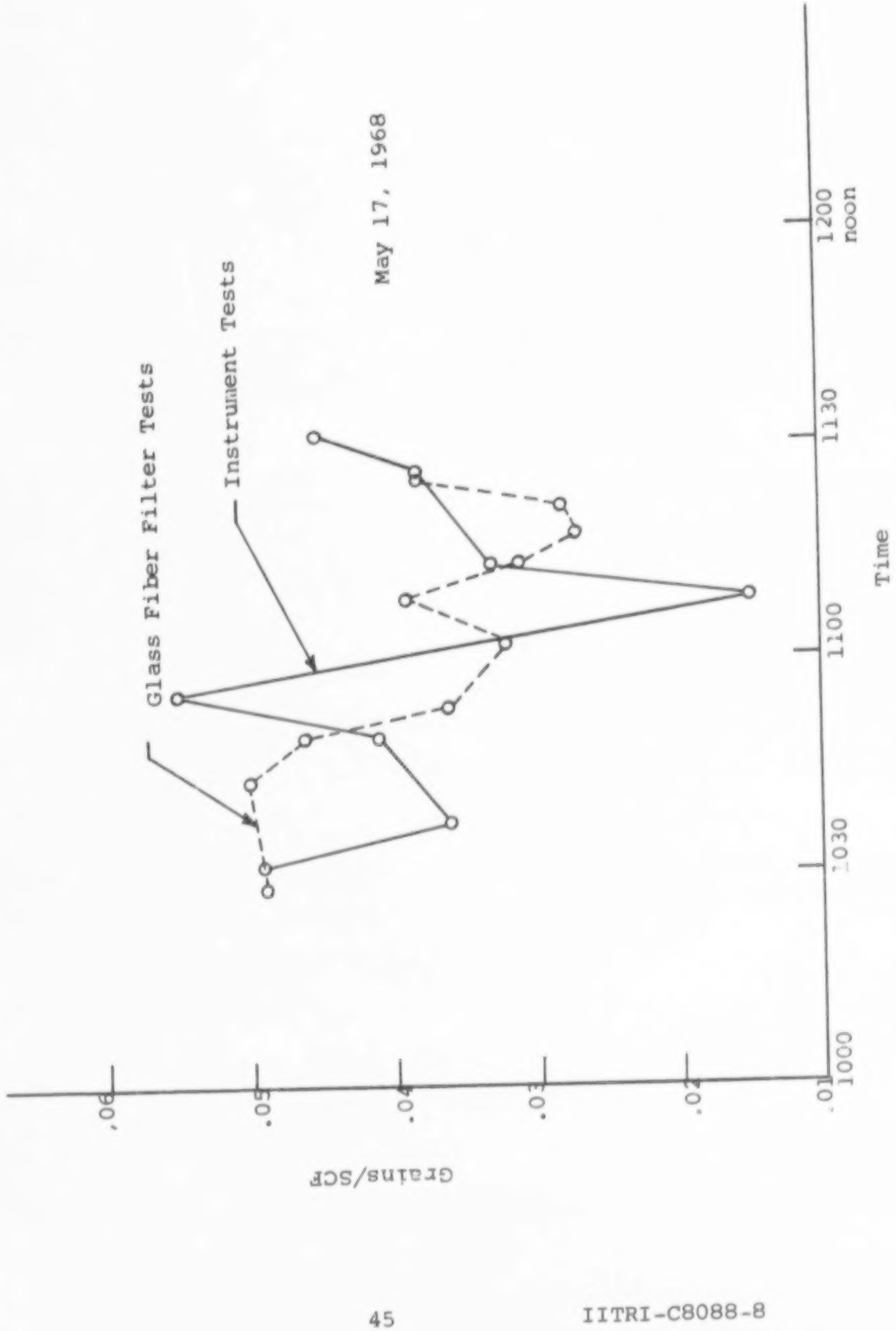


Figure 16

GLASS FIBER FILTER TESTS VERSUS INSTRUMENT TESTS

VII. RECOMMENDATIONS

Conceptually the systems employed in the prototype probed to be suitable for incinerator use. Certain modifications have, during the course of the field experience, suggested themselves: (1) Move the flow control valve to the clean side of the cyclone. (2) Provide easier access for visual inspection and manual cleaning of the sampling line, pitot lines, and cyclone. Easier access to the probe would offer at least two advantages. It would facilitate cleaning and installing additional probe sections and threrby effect multiple point sampling on an intermittent basis. (3) Increase the diameter of the sampling line (with consequent increase in the size of the cyclone separator) to accomodate macroscopic particles. (4) Provide more suction on the turbine sampling pump for completely effective sampling in stacks with high negative pressures. (5) Set up the beta gauge to assess and printout the value of the filter tape beta absorption immediately before sample deposition and thus eliminate the effect of variations in filter paper beta absorption characteristics. (6) Modify the program to allow for longer sampling periods. This will permit more effective monitoring of stacks with high temperatures and light dust burdens.

Further field investigational and monitoring effort is recommended following the modifications outlined above, principally to evaluate the effect of sample probe diameter and line loss on measured dust loadings.

After modification, extended field evaluations should be performed to collect operational experience which may be used by an instrument manufacturer as a guide to upgrading the laboratory design to make it suitable for commercial production. During this period close liaison with a suitable manufacturer is desirable.

VIII. CONCLUSIONS

This laboratory prototype monitor for fly ash emissions operated successfully through the field evaluations at three different incinerators. The monitor built and tested in this program is considered suitable with some modifications for commercialization by an experienced instrument manufacturer. It must be stressed that commercialization of a laboratory prototype instrument is a lengthy endeavor and any manufacturer will likely largely redesign the mechanical aspects of the prototype. Close liaison at this stage is necessary if this reorientation of design by the manufacturers is not to adversely affect the instrument operation and validity of measurement.

The field test data confirmed that there is no significant difference between samples collected under selected fixed or automatic isokinetic velocity conditions.

A consistant systematic difference between the data obtained using the monitor and by MCDAPC was observed and was attributed primarily to sample line loss. Selective elimination from the sample of very large particles may also have contributed to the observed systematic difference in measured stack dust loadings.

Recommendations have been made to elucidate and correct the exact cause of this systematic difference in measured loadings.

Further recommendations have been made for commercial development of the instrument.

Respectfully submitted,

IIT RESEARCH INSTITUTE

Walter A. Romanek.

Walter A. Romanek
Associate Engineer

R Jackson

Meryl R. Jackson
Manager
Fine Particles Research

Approved:

Eli S Freeman

Eli S. Freeman
Assistant Director
Chemistry Research

WAR:MRJ:sk
9/26/68

ACKNOWLEDGEMENT

The valuable assistance in the performance of this research effort of the cities in which the field evaluations were performed is acknowledged.

In particular we are indebted to Mr. Melbourne Noel and Mr. Kenneth Johnson of the City of Chicago, Mr. Bernard Geisheker, Mr. Fred Rehm, and Mr. Robert Redovich of the City and County of Milwaukee, and Mr. Anthony Cuciti and Mr. Sidney Jacobs of the City of New York.

The continuous assistance of the members of the steering committee is also appreciated. Particularly helpful in this regard have been the comments and constructive criticism of Mr. Samuel Clarke, Mr. John Nader, Mr. Herbert Poertner, and Mr. Robert Bugher.

DISTRIBUTION LIST

Copy No.	Recipient
1 - 70	American Public Works Association 1313 East 60th Street Chicago, Illinois 60637 Attention: Mr. H. G. Poertner Director of Research
71	IIT Research Institute Division C Files
72	IIT Research Institute Editors, D. J. McPherson, M. J. Klein
73	IIT Research Institute Main Files
74	IIT Research Institute Eli S. Freeman
75	IIT Research Institute T. R. Plonis
76	IIT Research Institute Walter A. Romanek

Appendix A
FIELD TEST INSTRUMENT OPERATION DATA

Appendix A

LIST OF TABLES

TABLE

Chicago

1 Instrument Operation, April 29
2 Instrument Operation, April 30
3 Instrument Operation, May 1
4 Instrument Operation, May 3
5 Instrument Operation, May 6
6 Instrument Operation, May 7
7 Instrument Operation, May 8
8 Instrument Operation, May 9
9 Instrument Operation, May 10
10 Instrument Operation, May 11
11 Instrument Operation, May 12
12 Instrument Operation, May 13
13 Instrument Operation, May 14
14 Instrument Operation, May 15
15 Instrument Operation, May 16
16 Instrument Operation, May 17
17 Instrument Operation, May 18
18 Instrument Operation, May 19
19 Instrument Operation, May 20

Milwaukee

20 Instrument Operation, May 21
21 Instrument Operation, May 22
22 Instrument Operation, May 23

New York

23 Instrument Operation, June 18

24 Instrument Operation, June 19

25 Instrument Operation, June 20

26 Instrument Operation, June 21

27 Instrument Operation, June 22

Table 1

INSTRUMENT OPERATION DATA
April 29, 1968

Number	Time	Mode	Grains/SCF
1	1003	I	.082
2	1009	F	.062
3	1043	I	.018
4	1048	F	.111
5	1134	I	.142
6	1140	F	.131
7	1319	I	.087
8	1324	F	.012
9	1414	I	.059
10	1420	F	.044
11	1433	I	.022
12	1438	F	.030
13	1451	I	.065
14	1457	F	.073
15	1510	I	.083
16	1515	F	.087
17	1529	I	.081
18	1535	F	.084
19	1548	I	.069
20	1553	F	.072
21	1614	I	.026
22	1620	F	.055
23	1627	I	.242
24	1632	F	.089
25	1638	I	.055
26	1646	F	.057

Averages:		
	Isokinetic mode	.079
	Fixed mode	.070
	Both modes	.075

Table 2

INSTRUMENT OPERATION DATA
April 30, 1968

Number	Time	Mode	Grains/SCF
27	1332	I	.128
28	1337	F	.035
29	1350	I	.004
30	1355	F	.036
31	1424	I	.073
32	1430	F	.056
33	1529	I	.038
34	1544	F	.083
35	1611	I	.067
36	1616	F	.049
37	1629	I	.025
38	1635	F	.044
39	1648	I	.065
40	1653	F	.042
41	1706	I	.053
42	1711	F	.018
43	1724	I	.036
44	1729	F	.047
45	1742	I	.076
46	1747	F	.014
47	1819	I	.022
48	1824	F	.030
49	1837	I	.068
50	1842	F	.081
51	1855	I	.065
52	1900	F	.040
53	1913	I	.021
54	1918	F	.100
55	1931	I	.014
56	1936	F	.031
57	1949	I	.013
58	1954	F	.012
59	2044	I	.046
60	2049	F	.014
61	2102	I	.017
62	2107	F	.037
63	2120	I	.021
64	2125	F	.027
65	2138	I	.021
66	2143	F	.074
67	2156	I	.020
68	2201	F	.038
69	2233	I	.057
70	2238	F	.002

Averages:		
	Isokinetic mode	.043
	Fixed mode	.041
	Both modes	.042

Table 3

INSTRUMENT OPERATION DATA
May 1, 1968

Number	Time	Mode	Grains/SCF
71	0003	I	.007
72	0008	F	.040
73	0022	I	.023
74	0027	F	.136
75	0040	I	.035
76	0045	F	.070
77	0058	I	.043
78	0103	F	.030
79	0116	I	.018
80	0121	F	.029
81	0134	I	.089
82	0139	F	.056
83	0152	I	.059
84	0157	F	.031
85	0210	I	.033
86	0215	F	.051
87	0228	I	.053
88	0234	F	.019
89	0304	I	.065
90	0310	F	.043
91	0323	I	.076
92	0328	F	.068
93	0341	I	.052
94	0346	F	.040
95	0359	I	.052
96	0404	F	.079
97	0417	I	.063
98	0423	F	.141
99	0435	I	.072
100	0441	F	.044
101	0453	I	.002
102	0459	F	.068
103	0512	I	.038
104	0517	F	.063
105	0530	I	.113
106	0535	F	.044
107	0548	I	.073
108	0554	F	.082
109	0606	I	.078
110	0612	F	.117
111	0625	I	.077
112	0630	F	.082
113	0643	I	.083
114	0648	F	.063
115	0701	I	.098
115	0706	F	.049

Table 3 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
117	0719	I	.028
118	0724	F	.089
119	0737	I	.082
120	0743	F	.080
121	0756	I	.092
122	0801	F	.021
123	0814	I	.035
124	0819	F	.018
125	0832	I	.104
126	0837	F	.113
127	0850	I	.077
128	0856	F	.073
129	0909	I	.091
130	0914	F	.076
131	0942	I	.039
132	0947	F	.065
133	1003	I	.080
134	1008	F	.067
135	1021	I	.062
136	1026	F	.064
137	1057	I	.057
138	1102	F	.024
139	1207	I	.056
140	1212	F	.123
141	1243	I	.004
142	1248	F	.011
143	1319	I	.088
144	1325	F	.089
145	1356	I	.084
146	1401	F	.116
147	1414	I	.107
148	1420	F	.103

Averages:	Isokinetic mode	.061
	Fixed mode	.066
	Both modes	.064

Table 4

INSTRUMENT OPERATION DATA
May 3, 1968

Number	Time	Mode	Grains/SCF
149	1450	I	.103
150	1455	F	.046
151	1510	I	.063
152	1515	F	.019
153	1532	I	.024
154	1537	F	.102
155	1608	I	.091
156	1613	F	.075
157	1654	I	.030
158	1659	F	.087
159	1740	I	.085
160	1745	F	.126

Averages:		
	Isokinetic mode	.066
	Fixed mode	.076
	Both modes	.071

Table 5

INSTRUMENT OPERATION DATA

May 6, 1968

Number	Time	Mode	Grains/SCF
161	1045	I	.102
162	1050	F	.069
163	1155	I	.063
164	1200	F	.060
165	1212	I	.108
166	1217	F	.065
167	1229	I	.014
168	1234	F	.069
169	1246	I	.030
170	1251	F	.065
171	1303	I	.071
172	1308	F	.080
173	1320	I	.060
174	1325	F	.086
175	1337	I	.118
176	1343	F	.063
177	1438	I	.039
178	1443	F	.058
179	1448	I	.070
180	1453	F	.038
181	1505	I	.101
182	1510	F	.082
183	1524	I	.096
184	1529	F	.081
185	1541	I	.063
186	1546	F	.046
187	1627	I	.069
188	1633	F	.070
189	1713	I	.100
190	1719	F	.079
191	1800	I	.092
192	1805	F	.118
193	1846	I	.112
194	1851	F	.091
195	1932	I	.091
196	1937	F	.103
197	2018	I	.111
198	2023	F	.067
199	2104	I	.093
200	2109	F	.089
201	2150	I	.093
202	2156	F	.098
203	2236	I	.072
204	2242	F	.078
205	2323	I	.048
206	2328	F	.078

Averages:	Isokinetic mode	.079
	Fixed mode	.078
	Both modes	.079

Table 6

INSTRUMENT OPERATION DATA
May 7, 1968

Number	Time	Mode	Grains/SCF
207	0009	I	.103
208	0014	F	.108
209	0055	I	.035
210	0100	F	.111
211	0141	I	.033
212	0146	F	.065
213	0227	I	.009
214	0232	F	.029
215	0313	I	.049
216	0318	F	.022
217	0359	I	.063
218	0404	F	.039
219	0531	I	.006
220	0537	F	.020
221	0947	I	.020
222	0623	F	.051
223	0704	I	.286
224	0709	F	.049
225	0750	I	.136
226	0755	F	.125
227	0836	I	.156
228	0841	F	.062
229	0922	I	.132
230	0927	F	.076
231	0947	I	.040
232	0953	F	.034
233	1005	I	.087
234	1011	F	.055
235	1023	I	.027
236	1028	F	.090
237	1041	I	.031
238	1047	F	.058
239	1100	I	.080
240	1105	F	.075
241	1118	I	.055
242	1123	F	.025
243	1136	I	.041
244	1141	F	.084
245	1154	I	.079
246	1159	F	.107
247	1212	I	.082
248	1217	F	.069
249	1230	I	.069
250	1235	F	.091
251	1248	I	.069
252	1253	F	.064

Table 6 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
253	1306	I	.004
254	1312	F	.067
255	1325	I	.079
256	1331	F	.086
257	1421	I	.051
258	1426	F	.070
259	1439	I	.090
260	1444	F	.077
261	1457	I	.066
262	1502	F	.048
263	1543	I	.071
264	1548	F	.062
265	1629	I	.112
266	1634	F	.055
267	1715	I	.035
268	1720	F	.071
269	1801	I	.021
270	1807	F	.091
271	1848	I	.015
272	1853	F	.035
273	1934	I	.070
274	1939	F	.065
275	2020	I	.096
276	2026	F	.065
277	2106	I	.043
278	2111	F	.039
279	2152	I	.104
280	2157	F	.061
281	2238	I	.049
282	2243	F	.102
283	2324	I	.056
284	2329	F	.044

Averages: Isokinetic mode .068
Fixed mode .065
Both modes .067

Table 7

INSTRUMENT OPERATION DATA
May 8, 1968

Number	Time	Mode	Grains/SCF
285	0020	I	.091
286	0025	F	.091
287	0106	I	.082
288	0111	F	.115
289	0152	I	.043
290	0157	F	.075
291	0238	I	.081
292	0243	F	.043
293	0324	I	.056
294	0329	F	.107
295	0410	I	.084
296	0415	F	.077
297	0456	I	.101
298	0501	F	.044
299	0542	I	.070
300	0548	F	.071
301	0629	I	.117
302	0634	F	.103
303	0715	I	.081
304	0720	F	.122
305	0801	I	.098
306	0807	F	.121
307	0848	I	.084
308	0853	F	.134
309	0934	I	.144
310	0940	F	.116
311	1020	I	.109
312	1025	F	.091
313	1106	I	.085
314	1111	F	.075
315	1123	I	.085
316	1130	F	.113
317	1210	I	.147
318	1215	F	.098
319	1254	I	.134
320	1259	F	.130
321	1339	I	.099
322	1344	F	.104

Averages:		
	Isokinetic mode	.094
	Fixed mode	.096
	Both modes	.095

Table 8

INSTRUMENT OPERATION DATA
May 9, 1968

Number	Time	Mode	Grains/SCF
323	1500	I	.045
324	1505	F	.033
325	1535	I	.050
326	1540	F	.018
327	1553	I	.001
328	1558	F	.007
329	1636	I	.013
330	1641	F	.036
331	1722	I	.044
332	1727	F	.110
333	1808	I	.039
334	1813	F	.030
335	1854	I	.067
336	1859	F	.080
337	1940	I	.051
338	1946	F	.112
339	2026	I	.075
340	2031	F	.085
341	2112	I	.045
342	2118	F	.073
343	2158	I	.063
344	2204	F	.001
345	2333	I	.036
346	2339	F	.014

Averages:		
	Isokinetic mode	.044
	Fixed mode	.050
	Both modes	.047

Table 9

INSTRUMENT OPERATION DATA
May 10, 1968

Number	Time	Mode	Grains/SCF
347	0019	I	.027
348	0025	F	.059
349	0151	I	.066
350	0157	F	.051
351	0237	I	.033
352	0243	F	.026
353	0323	I	.002
354	0329	F	.064
355	0409	I	.005
356	0415	F	.011
357	0455	I	.018
358	0501	F	.051
359	0542	I	.054
360	0547	F	.096
361	0628	I	.135
362	0633	F	.085
363	0714	I	.159
364	0719	F	.165
365	0800	I	.111
366	0805	F	.131
367	0846	I	.024
368	0851	F	.005
369	0932	I	.043
370	0937	F	.060
371	1109	I	.037
372	1115	F	.029
373	1155	I	.110
374	1201	F	.083
375	1241	I	.153
376	1247	F	.151
377	1318	I	.162
378	1323	F	.160
379	1336	I	.175
380	1341	F	.180
381	1354	I	.127
382	1400	F	.095
383	1418	I	.060
384	1424	F	.029
385	1439	I	.063
386	1445	F	.069
387	1457	I	.034
388	1503	F	.059
389	1516	I	.039
390	1521	F	.061
391	1534	I	.095
392	1539	F	.082

Table 9 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
393	1620	I	.068
394	1625	F	.117
395	1706	I	.044
396	1711	F	.069
397	1752	I	.047
398	1758	F	.106
399	1838	I	.059
400	1844	F	.058
401	1924	I	.059
402	1930	F	.099
403	2011	I	.040
404	2016	F	.005
405	2057	I	.047
406	2102	F	.006
407	2143	I	.093
408	2149	F	.051
409	2229	I	.002
410	2235	F	.011
411	2316	I	.009
412	2321	F	.015

Averages:		
	Isokinetic mode	.067
	Fixed mode	.071
	Both modes	.069

Table 10

INSTRUMENT OPERATION DATA
May 11, 1968

Number	Time	Mode	Grains/SCF
413	0048	I	.017
414	0053	F	.023
415	0134	I	.028
416	0140	F	.056
417	0220	I	.002
418	0226	F	.001
419	0353	I	.035
420	0358	F	.031
421	0439	I	.037
422	0444	F	.004
423	0525	I	.037
424	0531	F	.071
425	0658	I	.022
426	0703	F	.014
427	0916	I	.002
428	0922	F	.005
429	1049	I	.025
430	1054	F	.033
431	1135	I	.033
432	1140	F	.051
433	1221	I	.089
434	1226	F	.061
435	1307	I	.053
436	1312	F	.135
437	1353	I	.065
438	1359	F	.087
439	1439	I	.114
440	1445	F	.079
441	1526	I	.147
442	1531	F	.111
443	1612	I	.114
444	1617	F	.095
445	1658	I	.128
446	1703	F	.065
447	1744	I	.084
448	1749	F	.093
449	1830	I	.083
450	1835	F	.079
451	1916	I	.094
452	1922	F	.076
453	2002	I	.054
454	2008	F	.078
455	2048	I	.082
456	2054	F	.080
457	2134	I	.002
458	2140	F	.069

Table 10 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
459	2221	I	.030
460	2226	F	.065
461	2307	I	.068
462	2312	F	.073
463	2353	I	.043
464	2358	F	.111

Averages:	Isokinetic mode	057
	Fixed mode	.063
	Both modes	060

Table 11

INSTRUMENT OPERATION DATA
May 12, 1968

Number	Time	Mode	Grains/SCF
465	0039	I	.062
466	0044	F	.051
467	0125	I	.061
468	0131	F	.062
469	0212	I	.067
470	0217	F	.083
471	0258	I	.074
472	0303	F	.077
473	0344	I	.038
474	0349	F	.057
475	0430	I	.093
476	0436	F	.046
477	0516	I	.023
478	0522	F	.076
479	0603	I	.071
480	0608	F	.023
481	0649	I	.033
482	0654	F	.046
483	0735	I	.092
484	0740	F	.054
485	0821	I	.073
486	0827	F	.071
487	0907	I	.072
488	0913	F	.120
489	0953	I	.109
490	0959	F	.129
491	1040	I	.197
492	1045	F	.177
493	1126	I	.185
494	1131	F	.140
495	1212	I	.049
496	1217	F	.051
497	1258	I	.027
498	1303	F	.039
499	1430	I	.032
500	1435	F	.036
501	1734	I	.065
502	1739	F	.029
503	1820	I	.037
504	1825	F	.053
505	1906	I	.073
506	1911	F	.101
507	1952	I	.085
508	1957	F	.108
509	2038	I	.079
510	2043	F	.055

Table 11 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
511	2124	I	.115
512	2129	F	.093
513	2210	I	.133
514	2215	F	.062
515	2256	I	.075
516	2301	F	.040
517	2342	I	.066
518	2347	F	.071

Averages:		
	Isokinetic mode	.077
	Fixed mode	.072
	Both modes	.075

Table 12

INSTRUMENT OPERATION DATA
May 13, 1968

Number	Time	Mode	Grains/SCF
519	0028	I	.087
520	0033	F	.099
521	0114	I	.092
522	0119	F	.111
523	0200	I	.079
524	0206	F	.085
525	0246	I	.088
526	0252	F	.084
527	0332	I	.081
528	0338	F	.163
529	0419	I	.115
530	0424	F	.089
531	0505	I	.071
532	0510	F	.085
533	0551	I	.037
534	0556	F	.094
535	0637	I	.039
536	0642	F	.038
537	0723	I	.038
538	0728	F	.068
539	0809	I	.104
540	0814	F	.046
541	0855	I	.051
542	0901	F	.071
543	0941	I	.078
544	0947	F	.105
545	1007	I	.102
546	1013	F	.129
547	1034	I	.088
548	1039	F	.091
549	1100	I	.097
550	1105	F	.100
551	1130	I	.082
552	1145	F	.075
553	1232	I	.038
554	1237	F	.049
555	1318	I	.033
556	1323	F	.049
557	1404	I	.072
558	1409	F	.036
559	1426	I	.167
560	1535	F	.045
561	1551	I	.040
562	1556	F	.025
563	1612	I	.034
564	1617	F	.035

Table 12 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
565	1632	I	.045
566	1638	F	.042

Averages:	Isokinetic mode	.073
	Fixed mode	.076
	Both modes	.075

Table 13

INSTRUMENT OPERATION DATA
May 14, 1968

Number	Time	Mode	Grains/SCF
567	1630	I	.018
568	1635	F	.038
569	1746	I	.100
570	1752	F	.102
571	1903	I	.128
572	1908	F	.179
573	2019	I	.109
574	2024	F	.160
575	2135	I	.134
576	2140	F	.142
577	2251	I	.086
578	2256	F	.096
579	2317	I	.091
580	2323	F	.087

Averages:		
	Isokinetic mode	.095
	Fixed mode	.115
	Both modes	.105

Table 14

INSTRUMENT OPERATION DATA

May 15, 1968

Number	Time	Mode	Grains/SCF
581	0033	I	.113
582	0039	F	.094
583	0150	I	.074
584	0155	F	.055
585	0306	I	.036
586	0311	F	.082
587	0422	I	.044
588	0427	F	.026
589	0538	I	.077
590	0543	F	.074
591	0654	I	.112
592	0700	F	.210
593	0710	I	.157
594	0716	F	.182
595	1533	I	.023
596	1539	F	.009
597	1619	I	.022
598	1624	F	.005
599	1705	I	.003
600	1710	F	.065
601	1751	I	.025
602	1756	F	.023
603	1922	I	.031
604	1927	F	.025
605	2008	I	.066
606	2013	F	.034
607	2053	I	.023
608	2059	F	.033
609	2139	I	.020
610	2144	F	.023
611	2225	I	.008
612	2230	F	.005
613	2310	I	.014
614	2316	F	.057

Averages:		
	Isokinetic mode	.050
	Fixed mode	.059
	Both modes	.055

Table 15

INSTRUMENT OPERATION DATA

May 16, 1968

Number	Time	Mode	Grains/SCF
615	0042	I	.036
616	0047	F	.023
617	0127	I	.026
618	0133	F	.044
619	0213	I	.020
620	0218	F	.013
621	0259	I	.054
622	0304	F	.012
623	0344	I	.045
624	0350	F	.030
625	0430	I	.061
626	0435	F	.050
627	0516	I	.065
628	0521	F	.021
629	0602	I	.013
630	0607	F	.074
631	0647	I	.038
632	0653	F	.033
633	0733	I	.010
634	0738	F	.025
635	0819	I	.061
636	0824	F	.050
637	1455	I	.131
638	1501	F	.046
639	1726	I	.056
640	1732	F	.035
641	1842	I	.070
642	1848	F	.039
643	1959	I	.070
644	2004	F	.016
645	2115	I	.065
646	2120	F	.023
647	2347	I	.051
648	2352	F	.045

Averages:		
	Isokinetic mode	.051
	Fixed mode	.034
	Both modes	.043

Table 16

INSTRUMENT OPERATION DATA
May 17, 1968

Number	Time	Mode	Grains/SCF
649	0103	I	.021
650	0108	F	.067
651	0219	I	.010
652	0224	F	.077
653	0335	I	.035
654	0340	F	.049
655	0451	I	.033
656	0456	F	.040
657	0507	I	.020
658	0512	F	.040
659	0623	I	.033
660	0628	F	.018
661	0739	I	.026
662	0744	F	.072
663	0759	I	.017
664	0804	F	.033
665	0824	I	.031
666	0829	F	.076
667	0943	I	.054
668	0949	F	.028
669	1031	I	.049
670	1037	F	.036
671	1049	I	.041
672	1055	F	.055
673	1108	I	.015
674	1113	F	.033
675	1126	I	.038
676	1131	F	.045
677	1144	I	.025
678	1149	F	.039
679	1202	I	.010
680	1207	F	.039
681	1239	I	.052
682	1244	F	.045
683	1306	I	.017
684	1311	F	.029
685	1332	I	.041
686	1337	F	.020
687	1358	I	.052
688	1403	F	.074
689	1425	I	.008
690	1430	F	.048
691	1451	I	.034
692	1456	F	.058
693	1518	I	.038
694	1523	F	.010

Table 16 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
695	1540	I	.028
696	1546	F	.046
697	1630	I	.041
698	1636	F	.020
699	1716	I	.025
700	1722	F	.064
701	1802	I	.033
702	1808	F	.040
703	1849	I	.037
704	1854	F	.058
705	1935	I	.023
706	1940	F	.038
707	2021	I	.029
708	2026	F	.023
709	2107	I	.053
710	2112	F	.012
711	2153	I	.005
712	2158	F	.018
713	2239	I	.035
714	2244	F	.070
715	2325	I	.010
716	2330	F	.049

Averages:		
	Isokinetic mode	.030
	Fixed mode	.043
	Both modes	.037

Table 17

INSTRUMENT OPERATION DATA
May 18, 1968

Number	Time	Mode	Grains/SCF
717	0011	I	.019
718	0016	F	.037
719	0057	I	.007
720	0103	F	.028
721	0230	I	.025
722	0235	F	.054
723	0316	I	.047
724	0321	F	.071
725	0402	I	.041
726	0407	F	.037
727	0448	I	.012
728	0453	F	.058
729	0620	I	.035
730	0626	F	.022
731	0707	I	.094
732	0712	F	.029
733	0753	I	.045
734	0758	F	.064
735	0925	I	.023
736	0930	F	.033
737	1011	I	.061
738	1016	F	.014
739	1057	I	.035
740	1102	F	.047
741	1143	I	.014
742	1148	F	.014
743	1229	I	.005
744	1234	F	.011
745	1315	I	.047
746	1320	F	.008
747	1447	I	.058
748	1452	F	.049
749	1533	I	.022
750	1538	F	.024
751	1619	I	.035
752	1624	F	.049
753	1751	I	.047
754	1756	F	.069
755	1837	I	.016
756	1842	F	.037
757	1923	I	.025
758	1928	F	.052
759	2009	I	.012
760	2014	F	.049
761	2055	I	.024
762	2100	F	.043

Table 17 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
763	2141	I	.021
764	2146	F	.041
765	2227	I	.030
766	2232	F	.005
767	2313	I	.027
768	2318	F	.056

Averages:		
	Isokinetic mode	.032
	Fixed mode	.039
	Both modes	.036

Table 18

INSTRUMENT OPERATION DATA
May 19, 1968

Number	Time	Mode	Grains/SCF
769	0045	I	.036
770	0050	F	.068
771	0131	I	.014
772	0137	F	.047
773	0217	I	.046
774	0223	F	.017
775	0303	I	.025
776	0309	F	.065
777	0350	I	.007
778	0355	F	.046
779	0436	I	.027
780	0441	F	.061
781	0522	I	.059
782	0527	F	.068
783	0608	I	.033
784	0613	F	.030
785	0740	I	.013
786	0745	F	.052
787	0826	I	.031
788	0831	F	.027
789	0912	I	.039
790	0918	F	.051
791	0958	I	.060
792	1004	F	.035
793	1131	I	.038
794	1136	F	.031
795	1303	I	.011
796	1308	F	.011
797	1349	I	.029
798	1354	F	.039
799	1523	I	.028
800	1529	F	.050
801	1609	I	.047
802	1615	F	.023
803	1827	I	.043
804	1833	F	.014
805	1913	I	.008
806	1919	F	.010
807	1959	I	.061
808	2005	F	.058
809	2045	I	.035
810	2051	F	.045
811	2131	I	.032
812	2137	F	.066
813	2218	I	.019
814	2223	F	.022

Table 18 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
815	2304	I	.067
816	2309	F	.054
817	2350	I	.047
818	2355	F	.045

Averages:		
	Isokinetic mode	.034
	Fixed mode	.041
	Both modes	.038

Table 19

INSTRUMENT OPERATION DATA
May 20, 1968

Number	Time	Mode	Grains/SCF
819	0036	I	.063
820	0041	F	.025
821	0122	I	.071
822	0127	F	.045
823	0208	I	.050
824	0213	F	.055
825	0254	I	.033
826	0259	F	.060
827	0340	I	.039
828	0345	F	.043
829	0426	I	.021
830	0431	F	.054
831	0512	I	.046
832	0517	F	.025
833	0558	I	.029
834	0604	F	.008
835	0644	I	.069
836	0650	F	.031
837	0730	I	.043
838	0736	F	.067
839	0816	I	.044
840	0822	F	.026
841	0902	I	.038
842	0908	F	.042
843	0948	I	.034
844	0953	F	.022
845	1004	I	.070
846	1009	F	.104
847	1020	I	.094
848	1025	F	.098

Averages:	Isokinetic mode	.050
	Fixed mode	.047
	Both modes	.049

Table 20

INSTRUMENT OPERATION DATA
May 21, 1968

Number	Time	Mode	Grains/SCF
849	1746	I	.052
850	1751	F	.047
851	1800	I	.048
852	1805	F	.059
853	1851	I	.013
854	1857	F	.052
855	1937	I	.021
856	1942	F	.007
857	2109	I	.032
858	2114	F	.074
859	2154	I	.057
860	2200	F	.041
861	2240	I	.050
862	2245	F	.030

Averages:		
	Isokinetic mode	.039
	Fixed mode	.044
	Both modes	.042

Table 21

INSTRUMENT OPERATION DATA
May 22, 1968

Number	Time	Mode	Grains/SCF
863	0011	I	.029
864	0017	F	.030
865	0057	I	.044
866	0103	F	.012
867	0143	I	.036
868	0148	F	.005
869	0228	I	.015
870	0234	F	.009
871	0314	I	.021
872	0319	F	.012
873	0400	I	.048
874	0405	F	.028
875	0445	I	.043
876	0451	F	.053
877	0622	I	.034
878	0627	F	.027
879	0903	I	.095
880	0911	F	.036
881	0921	I	.029
882	0927	F	.061
883	1000	I	.041
884	1005	F	.069
885	1018	I	.041
886	1023	F	.019
887	1037	I	.038
888	1042	F	.126
889	1058	I	.133
890	1103	F	.131
891	1133	I	.080
892	1139	F	.122
893	1151	I	.112
894	1157	F	.147
895	1209	I	.085
896	1215	F	.097
897	1246	I	.106
898	1251	F	.073
899	1304	I	.077
900	1309	F	.097
901	1322	I	.088
902	1327	F	.092
903	1340	I	.075
904	1346	F	.080
905	1358	I	.112
906	1404	F	.144
907	1416	I	.081
908	1422	F	.101

Table 21 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
909	1434	I	.122
910	1440	F	.122
911	1453	I	.136
912	1458	F	.077
913	1511	I	.139
914	1516	F	.146
915	1529	I	.131
916	1534	F	.081
917	1547	I	.117
918	1552	F	.106
919	1605	I	.137
920	1611	F	.124
921	1623	I	.110
922	1629	F	.114
923	1641	I	.162
924	1647	F	.106
925	1659	I	.126
926	1705	F	.135
927	1745	I	.101
928	1751	F	.116
929	1832	I	.090
930	1837	F	.108
931	1918	I	.133
932	1923	F	.088
933	2004	I	.100
934	2009	F	.080
935	2050	I	.126
936	2055	F	.085
937	2136	I	.122
938	2141	F	.080
939	2222	I	.082
940	2227	F	.108
941	2308	I	.171
942	2313	F	.093
943	2354	I	.139
944	2359	F	.158

Averages:		
	Isokinetic mode	.090
	Fixed mode	.085
	Both modes	.088

Table 22

INSTRUMENT OPERATION DATA
May 23, 1968

Number	Time	Mode	Grains/SCF
945	0040	I	.125
946	0045	F	.100
947	0126	I	.133
948	0131	F	.126
949	0212	I	.112
950	0217	F	.103
951	0258	I	.143
952	0303	F	.113
953	0344	I	.134
954	0349	F	.091
955	0430	I	.137
956	0435	F	.077
957	0516	I	.107
958	0521	F	.124
959	0602	I	.106
960	0607	F	.131
961	0648	I	.109
962	0653	F	.122
963	0734	I	.146
964	0739	F	.109
965	0820	I	.151
966	0825	F	.074
967	0844	I	.151
968	0850	F	.103
969	0902	I	.140
970	0908	F	.125
971	0921	I	.119
972	0926	F	.103
973	0943	I	.109
974	0947	F	.082
975	0958	I	.112
976	1003	F	.133
977	1015	I	.155
978	1020	F	.140
979	1033	I	.183
980	1038	F	.140

Averages:	Isokinetic mode	.132
	Fixed mode	.111
	Both modes	.122

Table 23

INSTRUMENT OPERATION DATA
June 18, 1968

Number	Time	Mode	Grains/SCF
981	0738	I	.021
982	0742	F	.030
983	0847	I	.048
984	0851	F	.006
985	0952	I	.061
986	0957	F	.028
987	1103	I	.090
988	1108	F	.040
989	1125	I	.047
990	1130	F	.093
991	1140	I	.064
992	1146	F	.085
993	1156	I	.016
994	1201	F	.065
995	1212	I	.031
996	1217	F	.009
997	1231	I	.041
998	1236	F	.038
999	1321	I	.080
1000	1327	F	.048
1001	1342	I	.045
1002	1348	F	.037
1003	1403	I	.059
1004	1409	F	.084
1005	1429	I	.060
1006	1434	F	.004
1007	1455	I	.031
1008	1500	F	.014
1009	1521	I	.076
1010	1526	F	.047
1011	1546	I	.126
1012	1551	F	.079
1013	1612	I	.063
1014	1617	F	.037
1015	1638	I	.092
1016	1643	F	.062
1017	1703	I	.045
1018	1708	F	.051
1019	1729	I	.056
1020	1734	F	.052
1021	1754	I	.059
1022	1759	F	.118
1023	1820	I	.098
1024	1825	F	.095
1025	1840	I	.067
1026	1846	F	.070

Table 23 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
1027	1940	I	.053
1028	1946	F	.075
1029	2027	I	.059
1030	2032	F	.070
1031	2113	I	.047
1032	2118	F	.029
1033	2154	I	.037
1034	2159	F	.082
1035	2240	I	.057
1036	2245	F	.073
1037	2326	I	.042
1038	2331	F	.072

Averages:		
	Isokinetic mode	.058
	Fixed mode	.055
	Both modes	.057

Table 24

INSTRUMENT OPERATION DATA
June 19, 1968

Number	Time	Mode	Grains/SCF
1039	0012	I	.095
1040	0017	F	.088
1041	0058	I	.104
1042	0104	F	.055
1043	0145	I	.075
1044	0150	F	.098
1045	0231	I	.029
1046	0237	F	.050
1047	0317	I	.108
1048	0323	F	.048
1049	0404	I	.056
1050	0409	F	.097
1051	0450	I	.080
1052	0454	F	.085
1053	0535	I	.026
1054	0540	F	.080
1055	0622	I	.072
1056	0627	F	.058
1057	0708	I	.066
1058	0713	F	.065
1059	0749	I	.081
1060	0753	F	.022
1061	0829	I	.036
1062	0834	F	.083
1063	0905	I	.049
1064	0910	F	.097
1065	0926	I	.082
1066	0931	F	.095
1067	1020	I	.062
1068	1025	F	.058
1069	1045	I	.046
1070	1051	F	.068
1071	1111	I	.056
1072	1116	F	.085
1073	1148	I	.063
1074	1153	F	.080
1075	1250	I	.020
1076	1255	F	.046
1077	1321	I	.072
1078	1326	F	.041
1079	1351	I	.037
1080	1356	F	.053
1081	1420	I	.037
1082	1425	F	.101
1083	1457	I	.077
1084	1502	F	.026

Table 24 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
1085	1533	I	.084
1086	1539	F	.024
1087	1610	I	.066
1088	1615	F	.055
1089	1646	I	.030
1090	1652	F	.045
1091	1723	I	.095
1092	1728	F	.042
1093	1759	I	.066
1094	1804	F	.066
1095	1836	I	.048
1096	1841	F	.057
1097	1912	I	.065
1098	1917	F	.088
1099	1948	I	.033
1100	1954	F	.055
1101	2025	I	.020
1102	2030	F	.049
1103	2101	I	.062
1104	2107	F	.050
1105	2133	I	.040
1106	2138	F	.042
1107	2204	I	.022
1108	2209	F	.053
1109	2235	I	.019
1110	2240	F	.092

Averages:	Isokinetic mode	.058
	Fixed mode	.064
	Both modes	.061

Table 25

INSTRUMENT OPERATION DATA

June 20, 1968

Number	Time	Mode	Grains/SCF
1111	0109	I	.162
1112	0115	F	.083
1113	0146	I	.030
1114	0151	F	.066
1115	0222	I	.056
1116	0227	F	.076
1117	0258	I	.058
1118	0304	F	.062
1119	0335	I	.073
1120	0340	F	.092
1121	0411	I	.062
1122	0416	F	.013
1123	0447	I	.034
1124	0452	F	.060
1125	0518	I	.031
1126	0524	F	.049
1127	0555	I	.066
1128	0600	F	.072
1129	0631	I	.091
1130	0637	F	.045
1131	0708	I	.097
1132	0713	F	.091
1133	0744	I	.033
1134	0749	F	.083
1135	0815	I	.050
1136	0821	F	.035
1137	0847	I	.059
1138	0852	F	.053
1139	0918	I	.014
1140	0923	F	.039
1141	1033	I	.047
1142	1038	F	.032
1143	1101	I	.068
1144	1108	F	.091
1145	1118	I	.148
1146	1124	F	.076
1147	1248	I	.021
1148	1253	F	.083
1149	1305	I	.025
1150	1310	F	.069
1151	1322	I	.047
1152	1327	F	.013
1153	1339	I	.053
1154	1345	F	.078
1155	1351	I	.006
1156	1357	F	.057

Table 25 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
1157	1429	I	.041
1158	1435	F	.090
1159	1442	I	.041
1160	1447	F	.065
1161	1458	I	.070
1162	1503	F	.015
1163	1633	I	.038
1164	1638	F	.031
1165	1708	I	.044
1166	1714	F	.017
1167	1744	I	.047
1168	1749	F	.072
1169	1814	I	.057
1170	1819	F	.066
1171	1918	I	.076
1172	1924	F	.079
1173	1954	I	.079
1174	1956	F	.061
1175	2028	I	.055
1176	2033	F	.061
1177	2129	I	.057
1178	2134	F	.074
1179	2239	I	.110
1180	2244	F	.088
1181	2314	I	.050
1182	2319	F	.068
1183	2349	I	.045
1184	2354	F	.062

Averages: Isokinetic mode .058
Fixed mode .061
Both modes .060

Table 26

INSTRUMENT OPERATION DATA
June 21, 1968

Number	Time	Mode	Grains/SCF
1185	0024	I	.020
1186	0029	F	.036
1187	0059	I	.050
1188	0104	F	.042
1189	0134	I	.079
1190	0140	F	.022
1191	0209	I	.031
1192	0214	F	.068
1193	0239	I	.029
1194	0244	F	.063
1195	0340	I	.041
1196	0345	F	.064
1197	0416	I	.071
1198	0422	F	.046
1199	0518	I	.057
1200	0524	F	.049
1201	0653	I	.005
1202	0659	F	.003
1203	0728	I	.020
1204	0734	F	.033
1205	0804	I	.038
1206	0809	F	.047
1207	0938	I	.018
1208	0944	F	.016
1209	1039	I	.034
1210	1044	F	.044
1211	1205	I	.048
1212	1211	F	.037
1213	1233	I	.076
1214	1238	F	.062
1215	1307	I	.065
1216	1312	F	.059
1217	1404	I	.057
1218	1410	F	.081
1219	1536	I	.044
1220	1541	F	.136
1221	1616	I	.082
1222	1622	F	.081
1223	1702	I	.057
1224	1707	F	.095
1225	1747	I	.060
1226	1753	F	.124
1227	1833	I	.107
1228	1838	F	.057
1229	1918	I	.049
1230	1924	F	.063

Table 26 (cont'd)

INSTRUMENT OPERATION DATA

Number	Time	Mode	Grains/SCF
1231	2004	I	.089
1232	2009	F	.104
1233	2049	I	.087
1234	2055	F	.043
1235	2135	I	.037
1236	2140	F	.066
1237	2220	I	.124
1238	2226	F	.099
1239	2306	I	.058
1240	2311	F	.082
1241	2351	I	.070
1242	2357	F	.083

Averages:	Isokinetic mode	.055
	Fixed mode	.062
	Both modes	.059

Table 27

INSTRUMENT OPERATION DATA

June 22, 1968

Number	Time	Mode	Grains/SCF
1243	0037	I	.076
1244	0042	F	.051
1245	0122	I	.048
1246	0128	F	.048
1247	0208	I	.032
1248	0213	F	.033
1249	0248	I	.043
1250	0253	F	.125
1251	0328	I	.013
1252	0334	F	.028
1253	0414	I	.117
1254	0419	F	.096
1255	0459	I	.071
1256	0504	F	.089
1257	0544	I	.030
1258	0549	F	.038
1259	0629	I	.056
1260	0635	F	.103
1261	0715	I	.072
1262	0720	F	.084
1263	0800	I	.060
1264	0806	F	.078
1265	0846	I	.047
1266	0851	F	.067
1267	0931	I	.060
1268	0937	F	.066
1269	1017	I	.077
1270	1022	F	.081
1271	1102	I	.093
1272	1108	F	.153
1273	1148	I	.037
1274	1153	F	.065
1275	1228	I	.089
1276	1233	F	.076

Averages:		
	Isokinetic mode	.060
	Fixed mode	.075
	Both modes	.068

APPENDIX B

OPERATING MANUAL FOR THE FLY ASH MONITOR FOR MUNICIPAL INCINERATOR STACKS

IMPORTANT

1. This instrument contains a Promethium 147 radioactive source which is adequately shielded and safe to use in the proper manner.
2. The Promethium 147 radioactive source is a low energy source, (100 microcurie, maximum energy of .22 mev), and should be handled only by experienced personnel. The source is glass-fused and shielded. To indicate that the source has not been tampered with, the mounting screws of the beta gauge are sealed with paint.
3. Read these instructions before attempting to use this instrument.

1. INTRODUCTION

The purpose of the Fly Ash Monitor is to semi-continuously determine and record the mass fly ash particulate emissions from a municipal incinerator stack. The instrument measures, by a beta gauge gravimetric technique, the mass of fly ash contained in a pre-determined mass of stack gas.

The information output, namely beta attenuation and time at beta evaluation termination is presented in the form of a printed record. Thus, the sample is identified by time and the mass loading is calculated from the beta attenuation, pre-set parameter of mass of gas sampled, and the stack geometry.

2. DESCRIPTION OF THE MONITOR

The instrument is comprised of four basic modules:

1. Sampling probe
2. Sample analyzer
3. Pump station
4. Remote readout/control.

These are shown in Figures 1 and 2.

The probe section is comprised of an S-type pitot tube, a nozzle for extracting a gaseous sample, and a tube to transport the sample for evaluation. In operation this unit is inserted into a laminar region of the stack. A sample is taken from the stack and drawn down the sample tube into the sample analyzer module using a high volume exhaust pump.

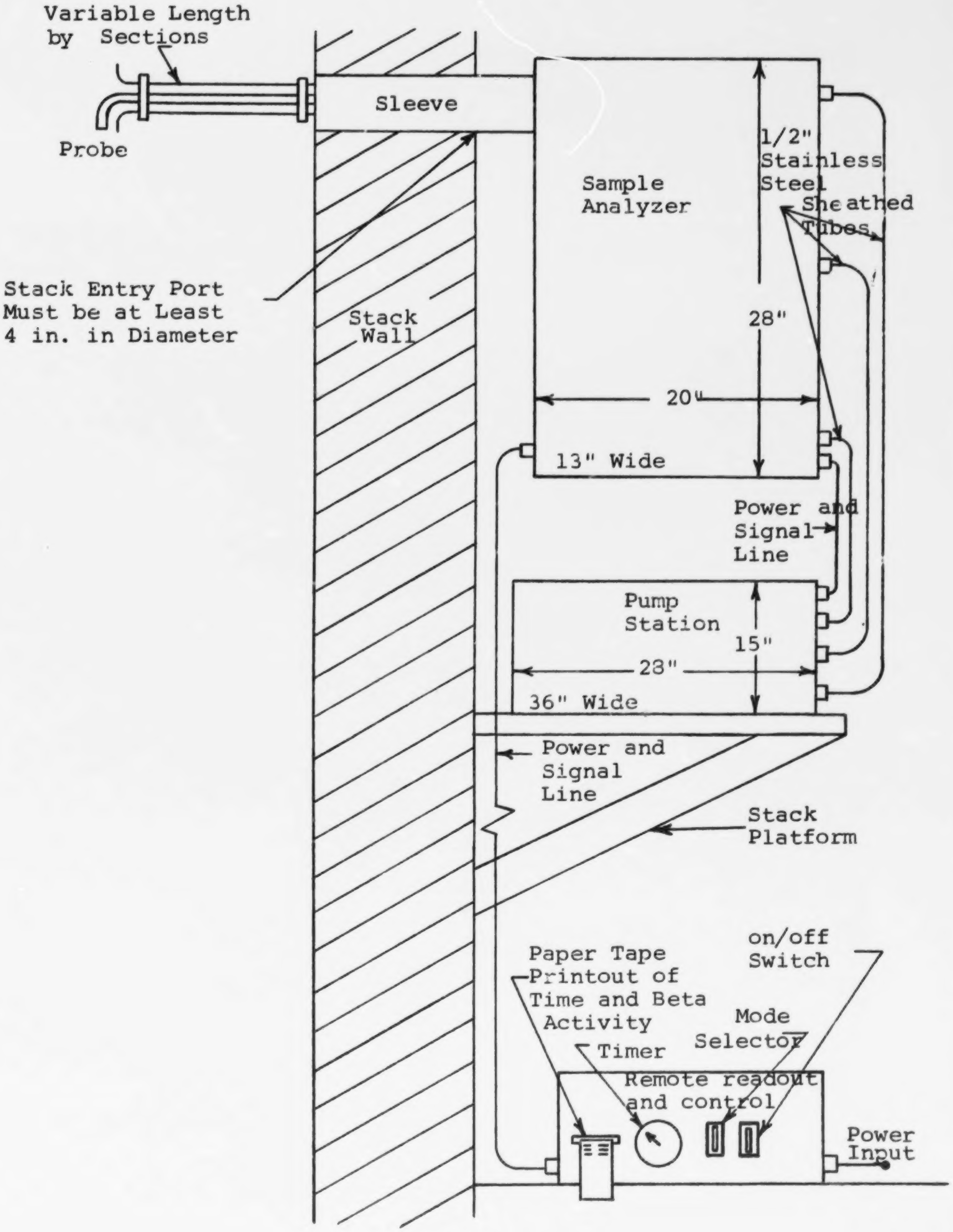

Variable Length by Sections
Probe
Sleeve
Stack Entry Port Must be at Least 4 in. in Diameter
Stack Wall
Sample Analyzer
1/2" Stainless Steel Sheathed Tubes
28"
20"
13" Wide
Power and Signal Line
Pump Station
15"
28"
36" Wide
Power and Signal Line
Stack Platform
Paper Tape Printout of Time and Beta Activity
on/off Switch
Mode Selector
Timer
Remote readout and control
Power Input

Figure 1

STACK INSTALLATION OF THE FLY ASH MONITOR

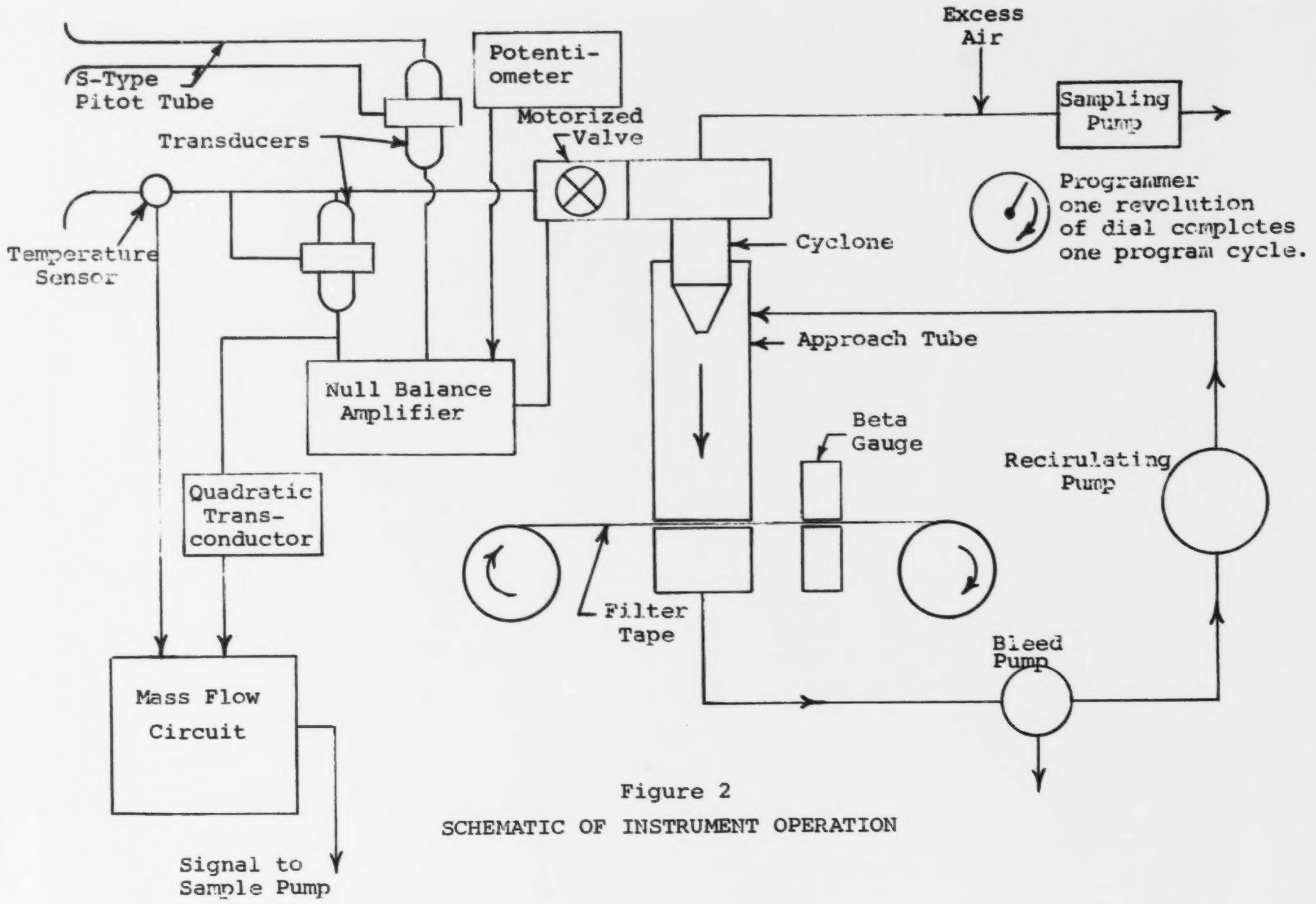

S-Type
Pitot Tube
Potenti-
ometer
Excess
Air
Sampling
Pump
Motorized
Valve
Transducers
Programmer
one revolution
of dial completes
one program cycle.
Temperature
Sensor
Cyclone
Approach Tube
Null Balance
Amplifier
Beta
Gauge
Recirulating
Pump
Quadratic
Trans-
conductor
Filter
Tape
Bleed
Pump
Mass Flow
Circuit
Signal to
Sample Pump

Figure 2
SCHEMATIC OF INSTRUMENT OPERATION

The suspended fly ash is removed from the stream by a high efficiency cyclone which acts as a primary collector. The fly ash sample is then deposited on a filter paper tape for mass assessment using a beta gauge technique. Provisions are incorporated for sampling either with a fixed sample velocity, or an automatic isokinetic velocity. Selection of the sampling mode, control of the instrument and readout facilities are provided in the readout/control module. The remote readout/ control module can be located up to 125 ft. away from the sampling and pump modules. This allows this unit to be conveniently situated, for example, at the base of the stack, or in a control room at any reasonable distance from the other units. The present limitation is at 125 ft. only because that is the length of the existing signal cable. In operation the sampling and pump station modules are located at the stack access port. The outside dimensions of the several modules are indicated on Figure 1.

The instrument is controlled from the remote unit. All power for the instrument is supplied to the remote module and distributed from there. The instrument is turned on and off and its operating mode is selected at the remote station. Three operating modes are available, (1) sampling at isokinetic velocity only, (2) fixed velocity only, or (3) both isokinetic and fixed velocity alternately.

The readout in the remote module prints out both the time at print out and the number of beta particles passing through the collected fly ash sample in the evaluation interval. This measure of beta activity is related by calibration to the mass of fly ash collected and thus the data characterizes the stack's emissions. To convert the measured sample mass to grains per cubic foot or pounds of fly ash per 1000 pounds of flue gas or any other expression, it is also necessary to know the stack geometry, the gas flow conditions, the unattenuated level of beta activity and the pre-set mass of gas sampled. Since in normal operation the base level of beta activity, pre-set mass of gas, and the stack geometry will be constant, the attenuated beta activity readout can be directly converted to grains per standard cubic foot with the use of a simple graph.

3. THEORY AND OPERATIONAL PRINCIPLES OF THE SEVERAL FUNCTIONS

Apart from the sampling of the stack gas stream, the fly ash monitor uses three distinct and separate physical processes in the determination of mass emissions from incinerator stacks. The first process is the separation of the particulate matter from the stack gas sample in a discrete, uniform deposition on a filter paper. The second process is the quantitative mass assessment of the sample deposition by a beta gauge technique. The third process is the sampling of a constant mass of stack gas.

3.1 Separation of Fly Ash From the Gas Stream

The particulates in the stack gas sample are separated from the gas by a centrifugal cyclone separator. The stack stream is sampled at some interior point in the stack and transported through the probe and throttling valve before reaching the cyclone. The sample is introduced into the cyclone tangentially. The pressure drop across the cyclone is independent of the concentration of fly ash in the stack gas sample, and thus gas flow rate is independent of dust loading.

From the base of the cyclone, the particles enter a dilution chamber which serves to disperse the sample so that it is uniformly deposited on the filter paper at the base of the dilution chamber. A slight downward flow of gas is always maintained in the dilution chamber to prevent fly ash re-entrainment.

The gas flow is properly balanced in the following manner. Pump A (Figure 3) continually recycles air across the filter tape. As the pressure drop across the filter tape increases by collection of fly ash, the recycling dilution air decreases. The vacuum at the base of the cyclone tends to create a net positive flow of gas from the dilution section to the cyclone. This condition is corrected by pumping a predetermined amount of air from the downstream side of the dilution system by pump B. Thus, at the worst operating condition (maximum fly ash deposit, highest leakage in pump bearing, and maximum vacuum at the base of the cyclone), pump B removes a quantity of air sufficient to ensure a slight downward flow of gas. This flow will vary from 0 to 4 liters/min. at a pressure drop of 0 to 20 in. Hg across the

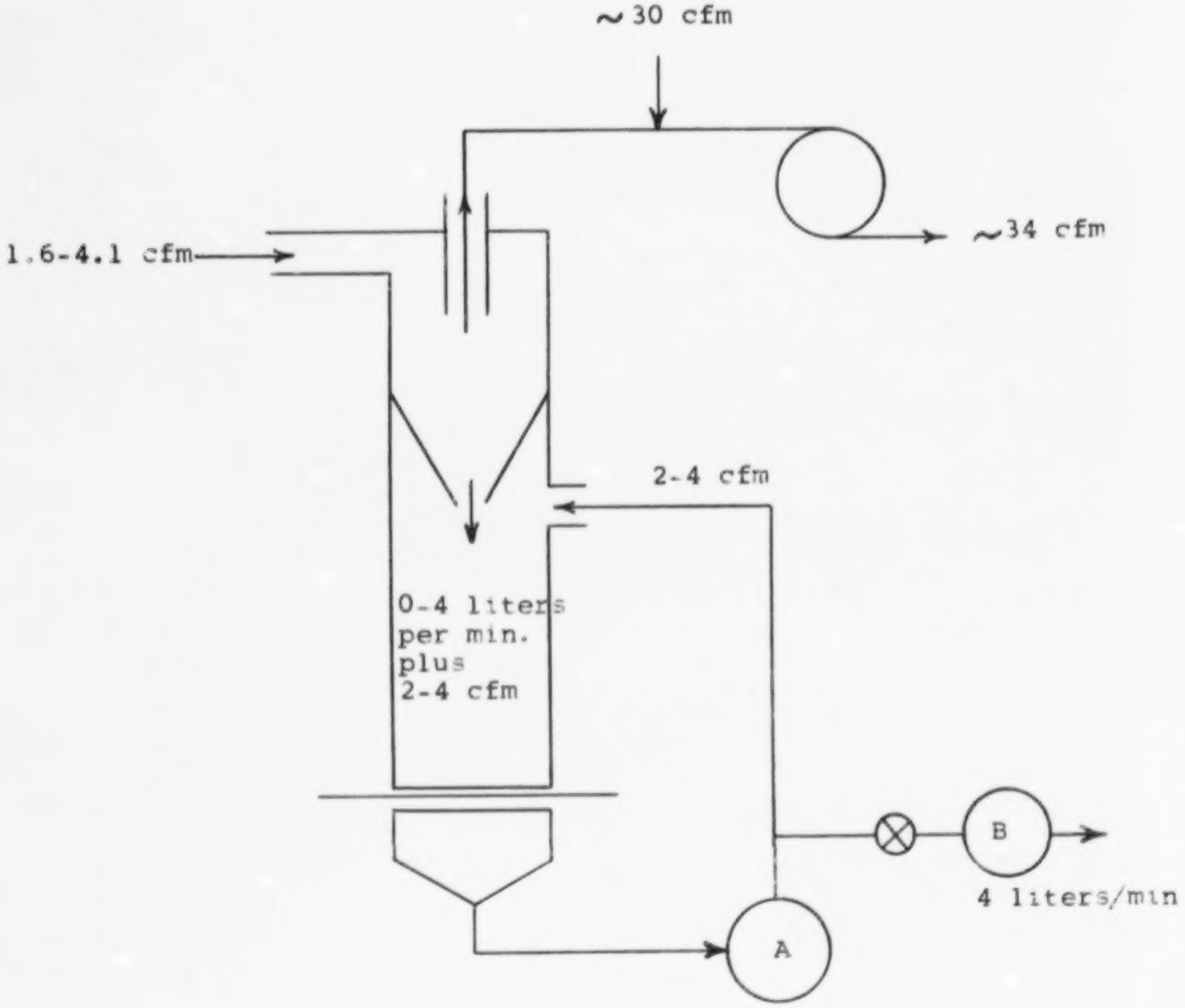

~30 cfm
1.6-4.1 cfm
~34 cfm
2-4 cfm
0-4 liters per min. plus 2-4 cfm
B
4 liters/min
A

Figure 3

INTERLOCKING FLOW SYSTEM

filter. Thus, the flow of pump B is adjusted to meet the worst physical conditions, i.e., 20-inch Hg pressure drop across the tape, which requires a 4-liter/min. bleed rate. This flow is preset with a needle valve and the setting remains constant throughout the period of operation of the instrument.

3.2 Assessment of Fly Ash By Beta Gauge

Immediately after sampling, the uniformly deposited fly ash sample is moved and positioned under a Promethium 147 beta emitting source. For an interval of two minutes and forty-five seconds, the amount of beta transmission through the fly ash sample and filter tape is measured by a GM tube. The distance between the source and filter tape is such that the area subtended by the beta rays is a circle approximately 1/4-inch in diameter. The amount of beta transmission through the filter tape alone is previously determined. The transmission through the combination of fly ash sample and tape is less than the transmission through the clean tape. The collected mass is related to this beta attenuation by a previous calibration of the beta gauge. The beta attenuation is printed out at the remote module along with the time of printout. A printout could look as follows:

```
10  21  38          928
```

This means that the fly ash sample was evaluated ten hours, twenty-one minutes and 38 seconds from time zero on the clock, (which may be reset to zero at any convenient time), and that the beta transmission through the sample was 928 in arbitrary count units. Assuming that the beta transmission through the clean filter tape was 1000, the transmission is

92.8 %. Reading the calibration graph, Figure 4, it is seen that the mass of collected fly ash is .55 milligrams per square centimeter. The total fly ash sample is determined by multiplying the figure from the graph by the total area of the fly ash deposition. That is, the 0.55 mg/cm^2 is multiplied by 20.3 cm^2. The total fly ash collection for this sample is 11.1 mg. Assuming that 3 standard cubic feet (SCF) of stack gas were preset as the gas sample, the grain loading is 0.057 grains per standard cubic foot. This figure is obtained as follows:

$$(11.1)\text{mg. fly ash } (.01543)\ \frac{\text{grains}}{\text{mg.}}\ \frac{1}{3\ \text{SCF}} = .057\ \frac{\text{grains}}{\text{SCF}}$$

3.3 Mass of Gas Sampled

The mass flow system samples a known volume of stack gas at standard conditions, i.e., a known mass of gas. The mass flow system measures the pressure drop across a segment of the sampling probe, measures the temperature of the sampled stack gas, takes account of the two variables of pressure drop and temperature and integrates the mass of sample with respect to time, and stops sampling when the integrated value is equal to a preset value.

3.4 Programmer

The monitor operates automatically through a preset program. Three modes of operation, or three programs can be preselected. They are:

1. Isokinetic only - samples are abstracted from the stack at an automatic isokinetic velocity,
2. Fixed veloxity only - samples are taken at a constant

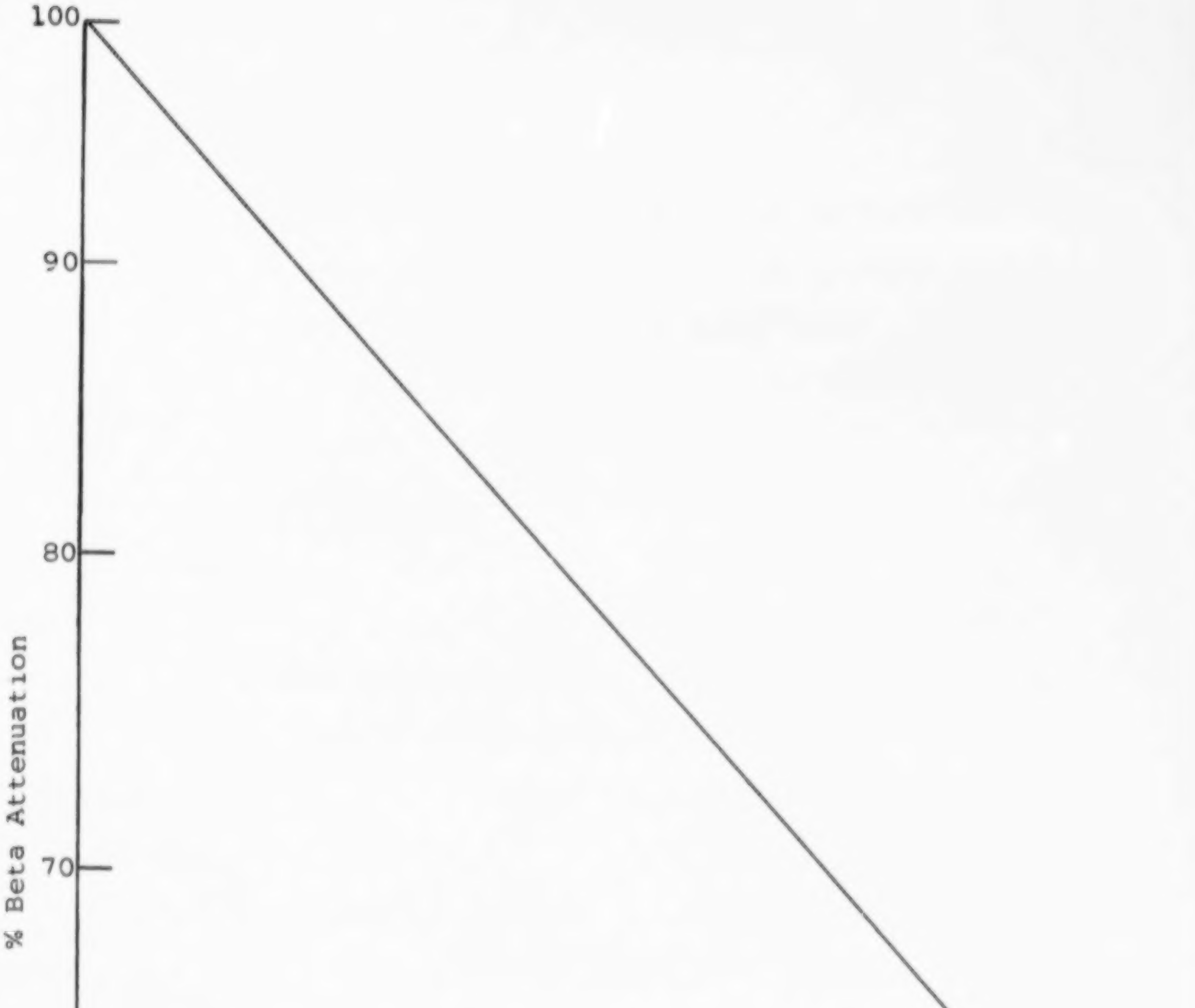


Figure 4

BETA GAUGE CALIBRATION

preset velocity.

3. Both - samples are drawn alternately at an isokinetic and fixed velocity. That is, an isokinetic sample is taken and immediately after the evaluation of the isokinetic sample, a fixed velocity sample is drawn and evaluated.

The program for sampling both isokinetically and at an invariant velocity is shown in Figures 5 and 6. The status of the program, i.e., where it is, is indicated by a dial position located in the sample analyzer module. The dial turns through one revolution for one complete cycle of the program. Thus, it is easy to visualize the various segments of the program as clock positions.

The programmer is simply a set of synchronous motor-driven, cam-operated switches. During the beta count and rest interval, the motor driving the programmer is de-energized and the programmer does not move.

The minimum time for one complete program is 16 minutes. The interval between cycles is selectable between 1 and 120 minutes and is determined by an interval timer. Setting the interval timer to its maximum of 120 minutes expands the period for one cycle to 136 minutes. That is, an isokinetic sample will be taken followed by a fixed velocity sample five minutes later. Approximately 126 minutes will elapse before the next isokinetic sample starts. In order to reduce the load on the monitor's pumps, they are automatically

Approximate Elapsed Time From Start	Program Position Indicator	Function
0	9 o'clock	Start isokinetic sample
2	10.5	Tape advance, initiate beta count
5	11.3	Reset beta and mass flow counters
	11.7	Start fixed velocity sampling
7	1.5	Tape advance, initiate beta count
10	2.5	Back flush sample line and other lines
12	4.0	Stop back flush of sample line, continue with back flush of pitot lines
15	8.0	Reset beta and mass flow counters
16	8.3	Start interval clock count-down

Figure 5

PROGRAM FUNCTIONS

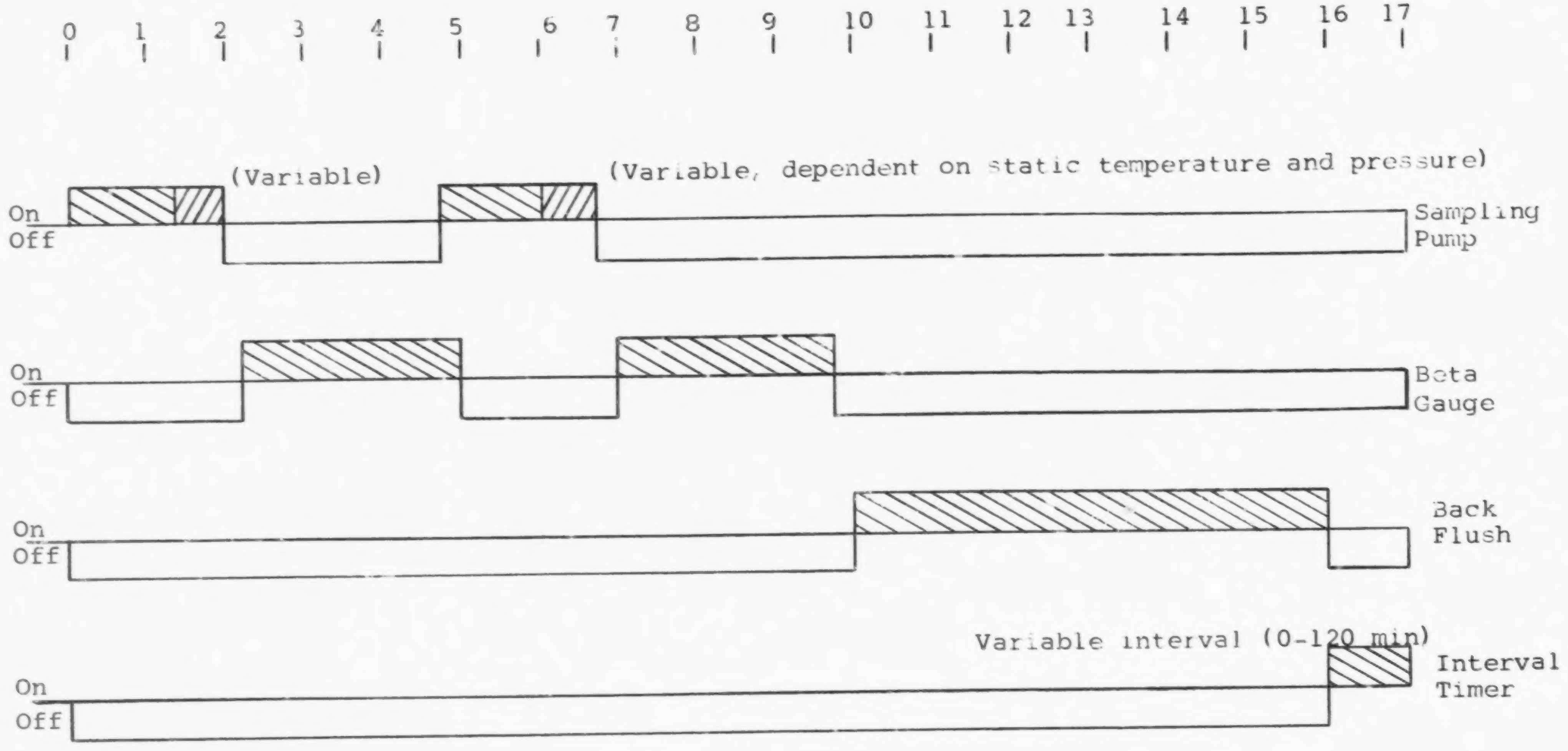


Figure 6

TIME SEQUENCE OF FUNCTIONS
WITH INTERVAL TIMER SET FOR 1 MINUTE

switched off during the interval between cycles. Thus, it is seen that the shortest period required to complete one program cycle is 16 minutes and the longest period during which one isokinetic and one fixed sample may be taken is 136 minutes.

4. SETTING-UP AND OPERATING PROCEDURE

4.1 Placement of the Modules

The sampling probe, sample analyzer, and pump station are positioned in and on the stack near the stack access port. The remote system readout/control module is positioned at any conveninet place away from the stack. The incinerator control room would be an excellent location for this module as the information printed out can readily be used to aid the proper firing of the incinerator.

The access port into the stack must be at least 4 inches in diameter. It must be at least 21 inches above the stack platform.

4.2 Connections

The four electrical cables and the three flexible, stainless steel sheathed tubes each have unique connections and can be connected only in a non-interchangeable way. They cannot be connected incorrectly.

Ensure that the main power switch on the remote readout/ control panel is in the OFF position, then connect

1. the signal and power cable between the remote and sample analyzer modules,

2. the signal and power cable between the sample analyzer and pump station,
3. the flexible gas flow lines between the sample analyzer and pump station,
4. the power cable between the remote module and a 110V, 60 cps supply capable of delivering 30 amps.

4.3 Sampling Probe

The sampling probe is assembled by sections. The initial section which connects to the sample analyzer module is four feet in length. Subsequent sections are three feet long. The first section is attached to the sample analyzer by six screws in a flanged butt connection with a teflon gasket. The first probe section contains the two pressure taps which measure the pressure drop and is heated with electrical tracing.

At the furthest in-stack point of this probe section, two thermal sensors are located. One is associated with the mass flow system and it is this temperature which is taken into account to determine the mass of gas sampled. The other thermal sensor is an auxiliary thermoresistive element which can be monitored with an ohmeter to indicate the probe temperature. This additional sensor can very easily be put into the mass flow circuit as a substitute if trouble develops with the sensor in the circuit.

The electrical tracing leads and thermal sensor ends are grouped together in a cable connector which must be connected with its mate in the sample analyzer module for proper operation. This connection should be made before the power to the monitor is turned ON.

The 4-inch O.D. anodized sleeve fits over this first probe section and is also attached to the flanged end of the sample probe.

Additional probe sections including the one containing the sampling nozzle and pitot tube openings are connected to the first section and each other with three screws and a copper gasket in flanged butt joints. Being of variable length by section, the probe can be used at various positions in the stack.

4.4 Filter Tape

Whatman no. 4 filter paper, chromatographic type, 2½-inch wide, is used as the fly ash collection media. The commercially obtained filter tape must be wound on new spools before it is used in the monitor. The roll of tape is inserted in the encolsed clean tape storage area of the sample analyzer module. The roll is loosely fitted and should be free-rolling. The filter tape is then simply fed through the sample block assembly by manually depressing the spring-returned filter closure. The tape is then passed through the tape drive and attached to the take-up reel with a piece of adhesive tape.

4.5 Operating Instructions

4.5.1 Turn main switch located on the remote panel to ON. This activates all circuits; the fly ash monitor is now in fully operational condition.

4.5.2 Adjust the time interval clock to the desired position between 0 and 120 minutes.

4.5.3 Turn the mode selection switch to the desired sampling condition. That is, select either isokinetic, fixed velocity, or alternately isokinetic and fixed velocity sampling.

4.5.4 Adjust the fixed velocity by turning the 10-turn indicating potentiometer on the front panel of the sample analyzer. Through ten turns the potentiometer moves from 0 to 1000. The range on the potentiometer from fully closed to fully opened valve is 600 to 740. These settings correspond to a velocity range of 20 to 50 fps.

4.5.5 The mass of gas sampled is selected by insertion of a number in the preset counter located on the front panel of the sample analyzer. One cubic foot of stack gas at standard conditions of 60°F and 29.9" Hg is sampled for each 44 counts set into the counter. That is, one hundred counts equals 2.3 cubic feet.

4.5.6 Upon completion of these steps, the instrument is in normal, automatic operation. It will continue to sample and evaluate the samples collected at the intervals indicated by the interval timer until it is turned OFF at the switch in the remote module.

4.6 Regular Maintenance

The regular maintenance requirements of the fly ash monitor are simple and few.

It is necessary to replenish the filter tape supply in the sample analyzer module at intervals. The filter tape is Whatman no. 4 filter paper, manufactured by W. & R. Balston, Ltd. It is available from most laboratory supply houses. With the instrument operating with an interval of one hour on the timer the filter tape will not have to be reloaded more often than once per week.

The paper tape and ink roller in the remote printer must also be replaced at intervals. This replacement will not occur more often than once every four months.

The only other item of routine maintenance is to brush out the probe, valve, and cyclone once every week. The probe is cleaned by disjoining at the sample analyzer and pushing a stiff-bristled, spiral brush down the length of the probe. If a compressed air supply is convenient, it can be used to blow back the probe line after it has been brushed. The cyclone is brushed by using the plugged opening in the tee at the top of the cyclone. The valve is best cleaned by putting a brush through the assembly from the front opening made clear by disjoining the probe. The total time requirement for this weekly cleaning should not exceed four hours.

Appendix C

INDEPENDENT DUST EMISSION TEST METHODS

INDEPENDENT DUST EMISSION TEST METHODS

INTRODUCTION

Independent tests were performed in Chicago and Milwaukee during the time when the fly ash monitor was field tested. The test results are discussed in the body of the final report, this appendix describes the test procedures used in each instance.

The Milwaukee tests were performed by the Milwaukee County Department of Air Pollution Control (MCDAPC) under the direction of Mr. F. Rehm. The description of procedure and other information relating to the Milwaukee tests is presented as Part I of this appendix and is reproduced directly from the MCDAPC test report by permission of Mr. F. Rehm.

The Chicago tests are described in Part II of this appendix.

PART I

Report of Dust Emission Tests
City of Milwaukee South Side Incinerator
American Public Works Assc.
Field Test of Flyash Monitor
June 22, 23, 1968

Introduction

The Illinois Institute of Technology under sponsorship of the American Public Works Association has developed a flyash monitor. A prototype of the monitor has been undergoing developement tests including field tests on actual incinerator applications. The prototype was installed and operated at the City of Milwaukee South Side Incinerator as a test on a batch type incinerator. While the monitor was in operation, tests were made to determine the dust concentration for comparison with the monitor. Three dust emission tests were made on June 22, and 23, 1968. This is a report of the results of the dust emission tests.

Description of plant

The plant consists of two separate 150 ton/day incinerating units connected to a common natural draft stack. The incinerators are batch fed from hoppers located above the furnace. The incinerator construction is conventional consisting of a furnace, combustion chamber, bridgewall, baffles, and breeching. Auxiliary gas firing is provided which is seldom used.

The gasses are partially cleaned as in conventional incinerators by changes in gas velocity, and changes in gas direction to induce settling out, and impingement of dust. However, the principal specific dust collecting device is an arrangement of wetted baffle plates located in the breeching of each unit before entering the common chamber at the entrance to the stack. These Detrick - Jens baffle plates are continually wetted and dust is collected by impingement on these plates. The dust collected is carried away in a water slurry to a classifier where the dust is removed. The water is chemically treated and reused in the dust collection system. Figure 1 is a schematic sketch of the incinerator arrangement. The wetted baffle arrangement is shown in Figure 2.

Description of Test Procedure and Equipment for Dustloading Tests

The Milwaukee County Air Pollution Control Department conducts dustloading tests in conformity with the A.S.M.E. Power Test Codes PTC-21-1941, "Test Code for Dust-Separating Apparatus" and PTC-27-[illegible]-1957, "Determining Dust Concentration in a Gas Stream." All of the tests herein reported were conduted in compliance with these codes. The A.S.M.E. Test Codes spell out in detail the procedure to achieve these basic objectives:

1. Securing a truly representative sample of the gases and suspensoids from the duct or stack.
2. Filtration and measurement of the particulates contained in the sampled gases.
3. Measurement of the sampled gas volume.
4. Measurement of duct conditions as to temperature, pressure, and composition of the effluent gases at the sampling point. Discussing each of these items:

1. Representative Sampling: Sampling openings were provided in the stack approximately 45' above grade. Two openings were provided at 90° to one another for taking dust samples. The stack cross-section was divided into five equal areas. A sample was taken for eight minutes at the center of a 90° sector of each of the equal areas, over half of the stack cross section, through both ports. The gross sample, was representative of half of the cross section. Between the two openings provided for the flyash monitor. See Figure 3 for a pictorial representation of the above.

An isokinetic sample was obtained by virtue of a balanced static tube method of sampling. This method involves the continuous adjustment of the sampling rate so that the velocity in the duct or stack is equalled by the velocity entering the sampling nozzle at all times. A specially designed stainless steel sampling nozzle of 1 1/4" inside diameter was used in the performance of these tests.

2. Filtration of Sampled Particulates: A modified Aerotec type sampler was used to collect the particulates in the sampled gas. The sampler consists of a 1 1/2" diameter stainless steel cyclone which precipitates the larger particulates into a tarred glass hopper jar and a tarred bag filtration unit where the fines are removed from the sampled gases. The total sample is the combined catch of these two units, together with that flushed from the sampling train at the conclusion of the test run.

3. Sampled Gas Volume Measurement: The sampled gas volume was measured in two different ways. One method incorporated the calibrated pressure drop across the sampler unit. The second method involved the use of a calibrated sharp-edged steel orifice in the flow passage of the sampled gas. The average sampled volume, as determined by these two methods was used in the subsequent dust-loading calculations.

4. Related Measurements: Temperature, pressure and gas conditions were measured using conventional equipment. A portable continuous carbon dioxide (CO_2) meter was used to determine the carbon dioxide content. Orsat analyses of the flue gas served as a check on the CO_2 meter. Mecurial thermometers and thermocouples and pyrometers were used in the temperature measurements. Manometers, inclined draft gauges, and an aneroid barometer were used in making draft and pressure measurements.

Accompanying this report is Figure 4 which depicts the equipment used and measurements taken during a dustloading test.

Operating and Test Conditions

During the tests, the plants were operated under normal operating conditions. Operating procedures and rate of charging were as carried out as regular day to day operation. Two dust emission tests were made on May 22, 1968 and one on May 23, 1968.

There is no convenient method of measuring rubbish feed to the incinerator by either volume or weight to determine the average firing rates over short periods of time. A check was made by counting the number of of loading crane bucket dumps into the hoppers and the hopper loads into the furnace. Based on this approximate measure the feed to the incinerators was judged to be approximately the same during each of the tests. The composition of the rubbish was variable. At the rate of 1000#/charge (average from earlier tests), the incinerators were being fired at an approximate rate of 10 tons/hour during the three tests.

Test Results

The results of the dustloading tests are tabulated in Table 1, Summary of Dustloading Determinations. The dustloading is expressed in commonly used units under actual dustloading conditions and as corrected to 12% CO_2.

One velocity and volume test was made on May 23, 1968, at 1:40 p.m. The volume measured was 161,000 cfm, at an average temperature of 690F°.

Report by:

R P Redovich

R. P. Redovich
Air Pollution Test Engineer

Approved by:

Fred R. Rehm

Fred R. Rehm
Director

Attachments
Figures 1, 2, 3, 4
Table 1

SUMMARY OF DUSTLOADING DETERMINATIONS
CITY OF MILWAUKEE - SOUTH SIDE INCINERATOR
FIELD TEST OF FLYASH MONITOR A.P.W.A. .

Test Run No.	Date & Time of Test	Conditions of Test	DUSTLOADING DETERMINATIONS — Actual Dustloading Encountered: Grains per cu. ft.	Grains per cu. ft. *SCTP	Lbs. of Dust per 1000# Gas	SAMPLING CONDITIONS: Temp F°	Press "Hg.	Gas Analysis - % CO$_2$	% O$_2$	% CO	% N$_2$	% H$_2$O	Corrected To 12% CO$_2$ (Dry): Grains per Cu. Ft.	Grains per Cu. Ft. *SCTP	Lbs. of Dust per 1000# Gas
1	5-22-68 12:25 p.m. to 2:13 p.m.	Normal Operation	.0645	.154	.290	690	29.24	3.1	13.7	0.0	66.4	16.8	.209	.499	.941
2	5-22-68 2:56 p.m. to 4:36 p.m.	Normal Operation	.0756	.179	.331	675	29.22	3.8	13.1	0.0	67.3	15.8	.202	.477	.883
3	5-23-68 9:26 a.m. to 11:20 a.m.	Normal Operation	.0856	.207	.385	698	29.15	3.1	14.1	0.0	67.6	15.2	.286	.690	1.28

*32F° , 29.92 "Hg

TABLE I

INCINERATOR ARRANGEMENT
CITY OF MILWAUKEE
SOUTH SIDE INCINERATOR

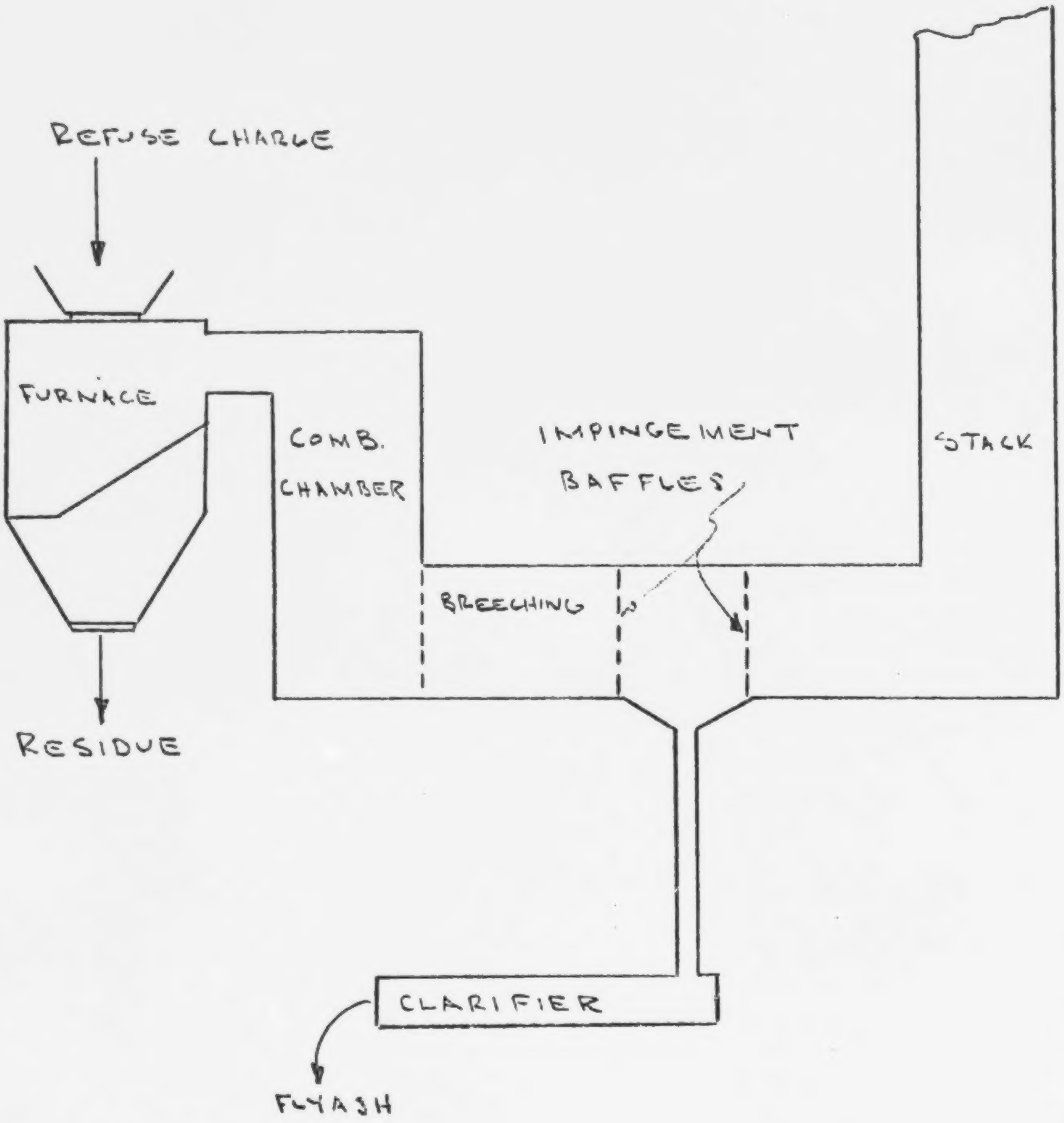
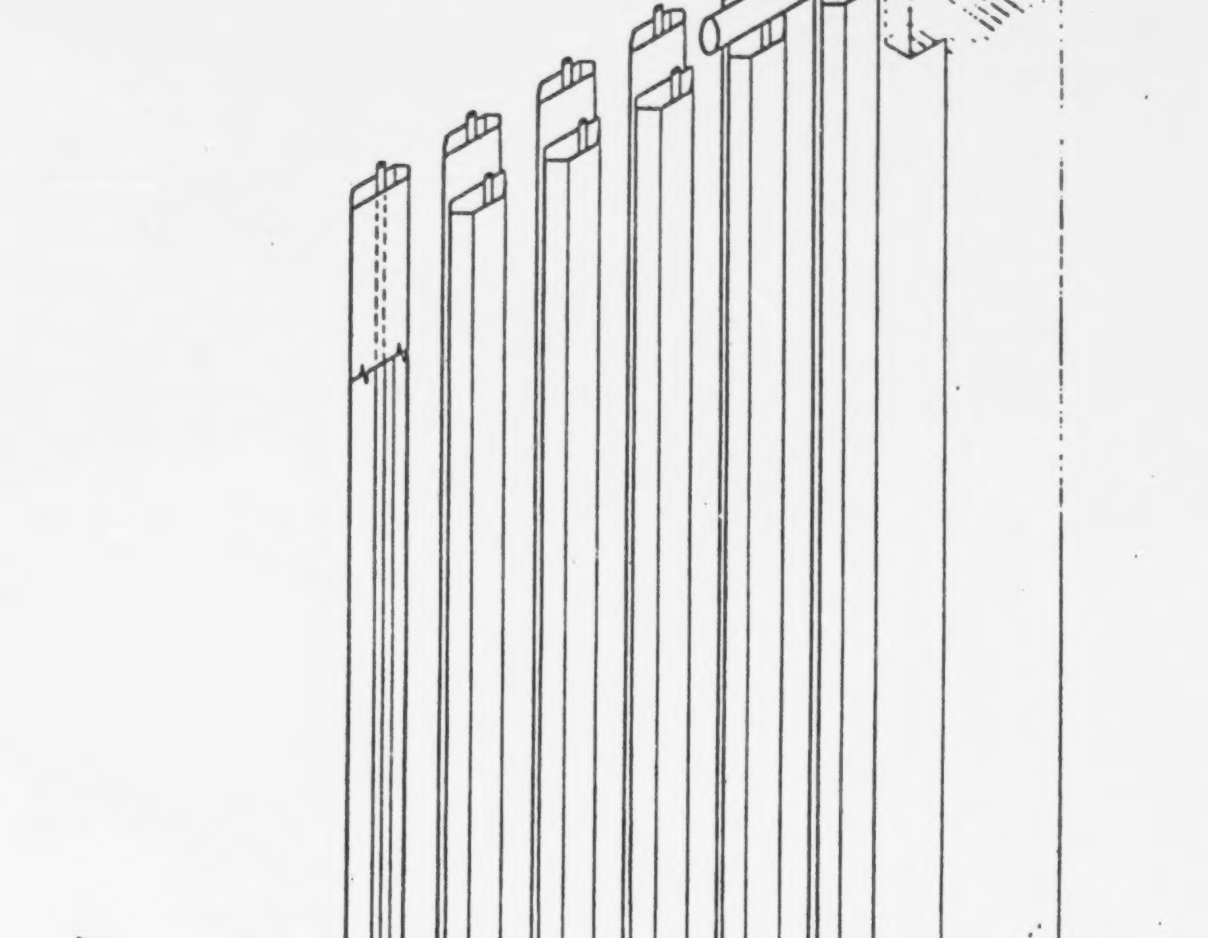
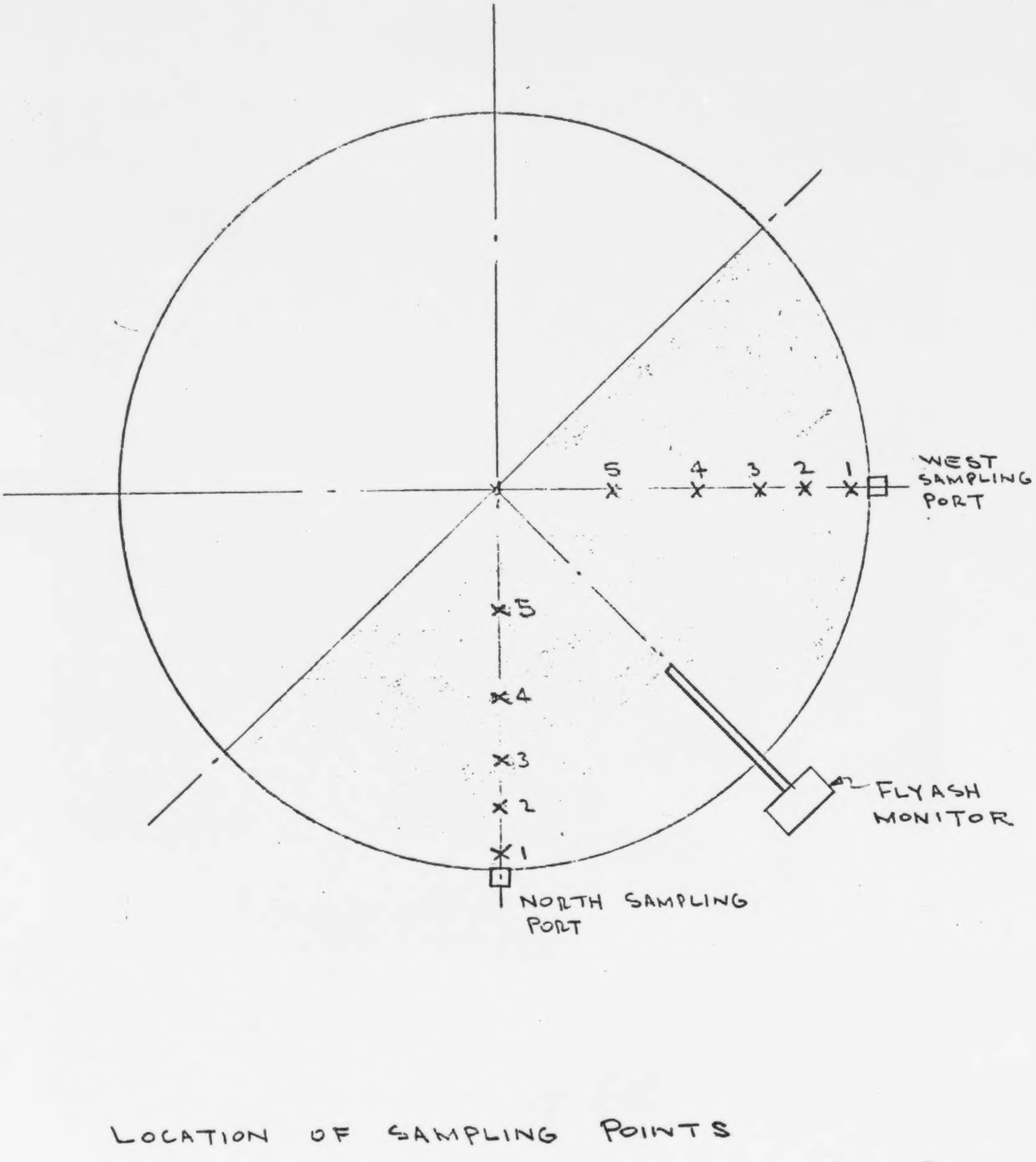

REFUSE CHARGE
FURNACE
COMB. CHAMBER
IMPINGEMENT BAFFLES
STACK
BREECHING
RESIDUE
CLARIFIER
FLYASH

FIG. 1



/ C7

FIG.2


5
4
3
2
1
WEST SAMPLING PORT
5
4
3
2
1
NORTH SAMPLING PORT
FLYASH MONITOR

LOCATION OF SAMPLING POINTS
AND FLYASH MONITOR

FIG. 3

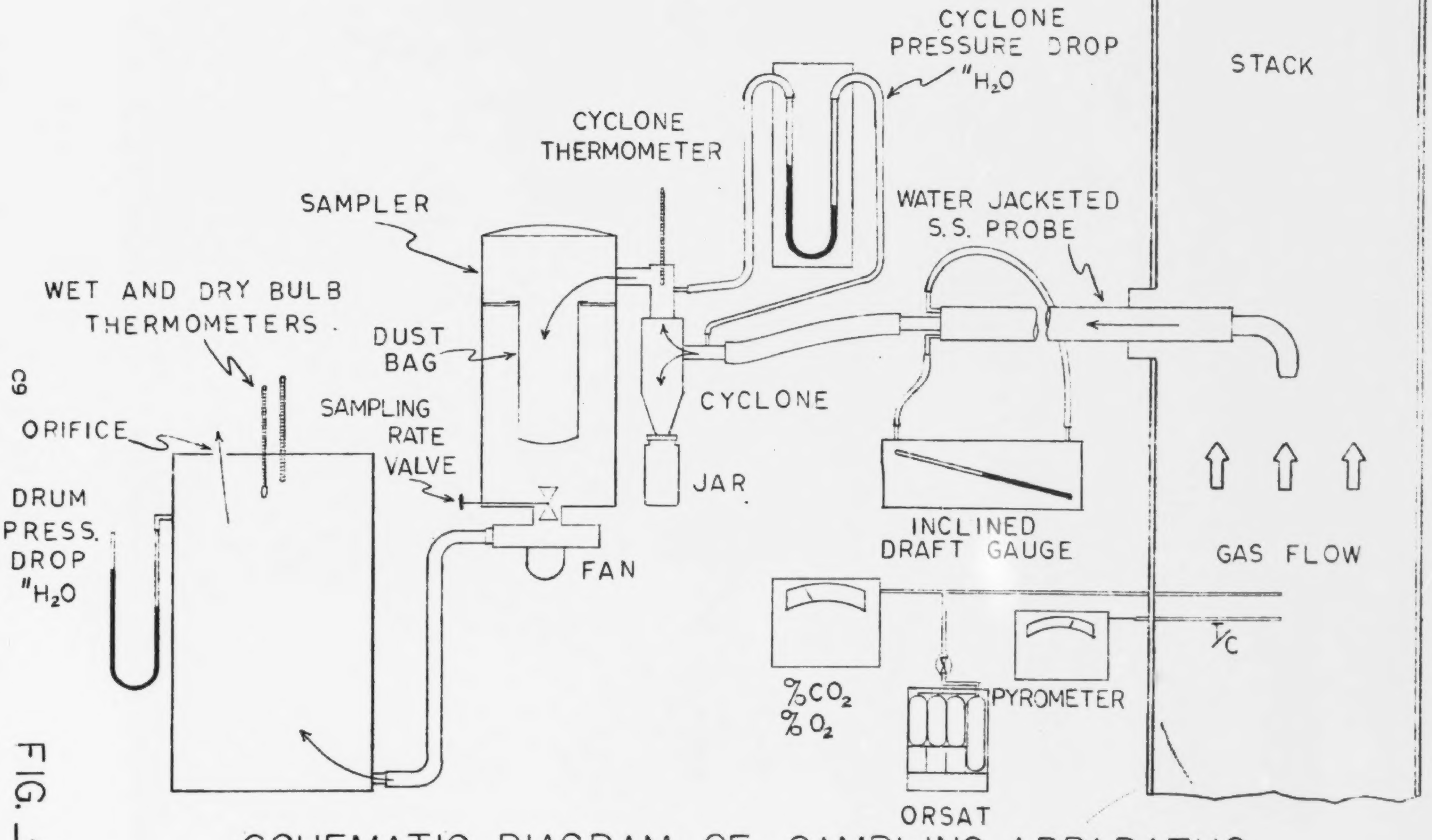

CYCLONE
PRESSURE DROP
"H_2O
STACK
CYCLONE
THERMOMETER
SAMPLER
WATER JACKETED
S.S. PROBE
WET AND DRY BULB
THERMOMETERS.
DUST
BAG
C9
CYCLONE
SAMPLING
RATE
VALVE
ORIFICE
JAR.
DRUM
PRESS.
DROP
"H_2O
INCLINED
DRAFT GAUGE
FAN
GAS FLOW
T/C
$\%CO_2$
$\%O_2$
PYROMETER
ORSAT

FIG. 4

SCHEMATIC DIAGRAM OF SAMPLING APPARATUS
STATIC BALANCED TUBE METHOD OF SAMPLING

PART II. DUST EMISSION TESTS IN CHICAGO

Equal Area Zones, Stack Velocity and Temperature

Before sampling, the stack cross-section was divided into six equal area annuli, and the center of each of these zones, as measured along a radius, was designated as a sampling point. The other radius on the same diameter was used for velocity and temperature measurements and the fly-ash monitor was positioned on a bisecting, perpendicular radius. These sampling positions are shown in Figure 1.

Velocity and temperature traverses were run before any testing was begun. A typical stack velocity profile is shown in Table 1. The west radius traverse shows an average stack velocity of 25.3 fps and an average stack temperature of 466°F.

The velocity of the stack gas stream was determined by using a "double-pitot", or S-type pitot, tube with a micromanometer. A total of 6 pitot traverse points located at the center of each equal annular area was used along each radius.

The temperature was determined at each traverse point with a chromel-alumel thermocouple which was located at the tip of the pitot tube.

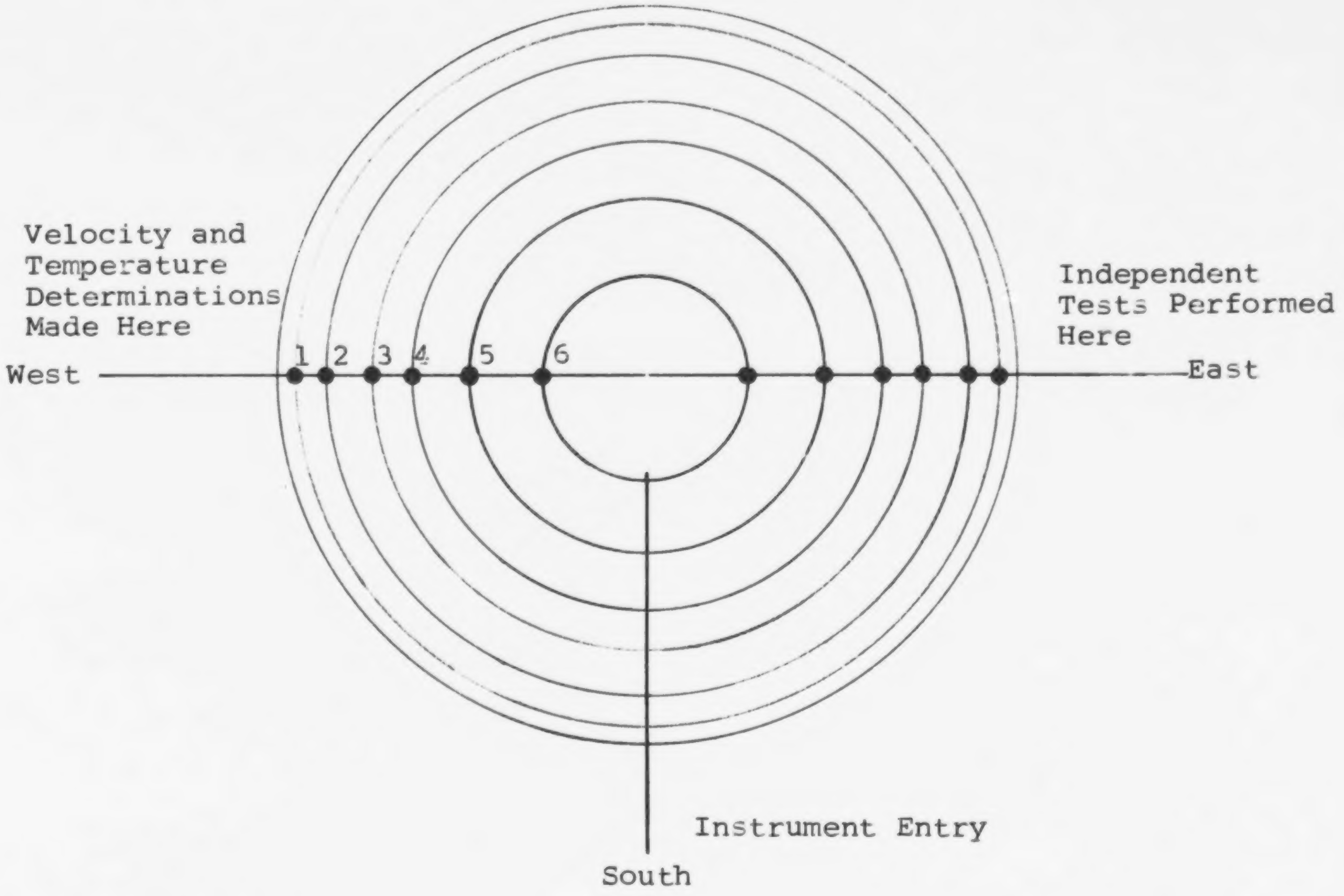

Velocity and
Temperature
Determinations
Made Here
Independent
Tests Performed
Here
West
East
1
2
3
4
5
6
Instrument Entry
South

Figure 1

PLAN VIEW OF SETUP AT
SOUTHWEST INCINERATOR, CHICAGO
SHOWING SIX EQUAL AREA SAMPLING ZONES

Table 1

STACK VELOCITY AND TEMPERATURE
(May 17, 1968)

Time, AM	Point	Velocity, fps	Temp., °F
9:35	East 1	20.2	427
	2	23.3	427
	3	24.0	436
	4	25.6	444
	5	25.2	438
	6	25.6	438
10:40	West 1	21.4	462
	2	25.0	466
	3	26.1	466
	4	27.2	471
	5	26.1	466
	6	26.1	466
	Average	25.3	466

SAMPLING METHODS

The ASME PTC 27 (1957) was used as a guide in setting up the sampling trains and performing the tests. Two different collecting elements were used. For the tests designated ceramic thimble tests, an alundum cartridge 1¼ x 4 in. was used as the collector. For the glass fiber filter tests the same sampling train was used except the thimble holder was modified to accomodate a glass fiber filter as the particulate collecting element.

From particulate entry point to sample gas exhaust the sampling train consisted of the following: one-half inch sharp-edged nozzle, thimble holder and thimble (modified to accomodate either a glass fiber filter or ceramic thimble), eleven foot section of ½" stainless steel pipe, thick-walled rubber hose, knock-out jar for condensate, orifice plate and manometer, control valve, dry gas meter, and exhaust pump. The sampling train is shown diagramatically in Figure 2.

The probe connected to the assembled sampling train was inserted into the stack with the nozzle opening pointed away from the direction of flow and kept in that position for a minute or two to allow the sampling probe to reach stack ambient temperature before sampling was begun. For a traverse sample the probe was then moved from point 1 sequentially to point 6 and back to point 1 with a two minute residence at each of the 6 sampling points. For a sample at point 6, the probe

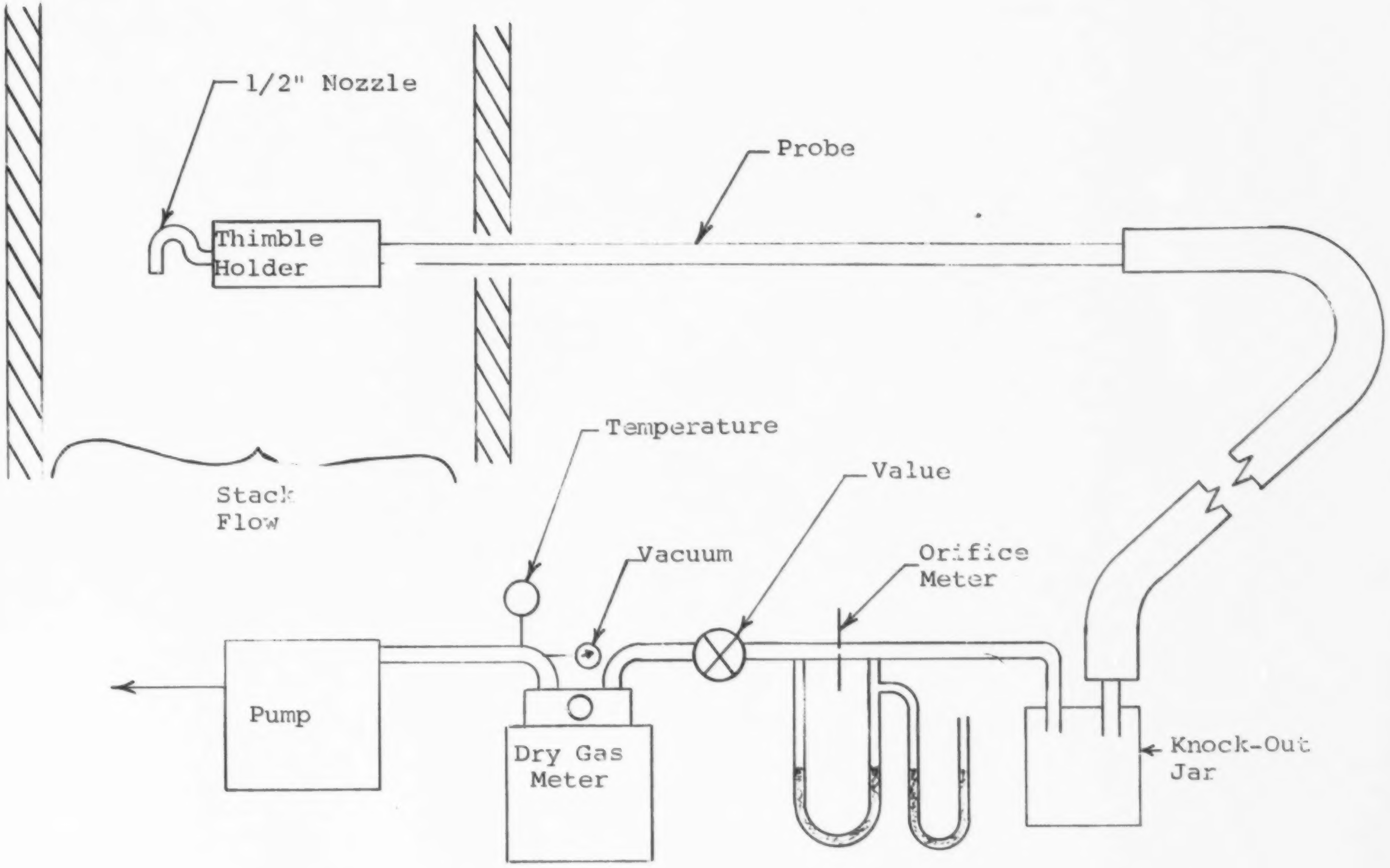

1/2" Nozzle
Probe
Thimble
Holder
Stack
Flow
Temperature
Value
Vacuum
Orifice
Meter
Pump
Dry Gas
Meter
Knock-Out
Jar

Figure 2

DIAGRAM OF SAMPLING TRAIN

and sampler were kept stationary at that one point for the duration of the run.

The nozzle velocity at which the stack stream was sampled corresponded to a pitot traverse run immediately prior to the dust loading test. The samples were thus obtained at an average isokinetic velocity.

The particulate collection was weighed on an analytical balance. Before weighing, the filtersused in these tests were equilibrated in the weighing room for at least 24 hours at ambient conditions both before and after use in the sampling train. The alundum thimbles were heated overnight in an 800°F oven before their original weighing and use. They were then equilibrated at ambient weighing room conditions and checked to ensure that they were at constant weight. After use, they were again equilibrated before reweighing.

The outstanding differences between the sampling procedures employed in Chicago and Milwaukee were (1) a small volume (3 to 20 SCF) of the stack stream was sampled in Chicago while the tests in Milwaukee sampled a relatively large volume of the stack stream (≈ 450 SCF) and (2) the cross-sectional area of the nozzle used in Milwaukee (1¼" I.D.) was much greater than that used in the Chicago tests (½" I.D.).

APPENDIX D

MONITOR PURCHASE AND OPERATING COST ESTIMATE

AND

LIST OF MANUFACTURERS IN THE AIR POLLUTION INSTRUMENTATION/CONTROL FIELD

MONITOR PURCHASE AND OPERATING COST ESTIMATE

Pricing an instrument is an esoteric art known only to instrument manufacturers and generally formal estimates are overriden by "what the market will bear".

Attempting to estimate the cost of manufacturing an instrument is impossible until a production prototype is nearing completion and a rigorous cost evaluation is performed. Not only do factors such as development cost, material, labor, and overhead loom importantly, but also the size of the ultimate market for the instrument is of great importance in calculating cost recovery and profit margins.

With deference to the above factors we cannot make a definitive cost estimate for manufacturing the APWA monitor. We may, however, by comparison with existing instrumentation infer a reasonable price range for the instrument.

Presently, there is only one automatic stack monitor on the market; the AISI automatic stack monitor sold by Research Appliance Company (Catalog No. 2345).

The AISI instrument is simpler than that developed for APWA in that the system operates only at fixed velocity, thus requiring no isokinetic control components. Additionally, the collection system in the APWA instrument is of necessity more complex than the Research Appliance Company instrument.

These factors are due entirely to the different operational requirements of the two instruments.

Bearing in mind the simpler aspects of the AISI instrument, at a cost of $7600, it is unlikely that the APWA instrument could be marketed for less than $10,000.

The cost of operation itself will be minimal. Appendix B indicates the regular maintenance required to operate the instrument. Apart from the small power requirement and a supply of filter paper, maintenance will constitute the only other operating cost. It is believed at this time that about 4 hours per week will be required for regular maintenance of a commercially produced instrument.

The following list of companies (in alphabetical order) are active in the air pollution instrumentation and/or air pollution control field and may have some interest in the development of the APWA monitor.

Airetron Engineering Corporation
190 Godwin Avenue
Midland Park, New Jersey 07432
(201)444-2615

American Air Filter Company, Inc.
633 S. 5th Street
Louisville, Kentucky 40202
(502)583-0262

American Instrument Company, Inc.
8030 Georgia Avenue
Silver Springs, Maryland 20910
(301)589-1727

AMSTRO Corporation
108 Clinton Road
Fairfield, New Jersey 07006
(201)228-3881

Applied Dynamics International
2275 Platt Road
Ann Arbor, Michigan 48104
665-3601

Bacharach Industrial Instrument Company
700 Bennett Street
Pittsburgh, Pennsylvania

Beckman Instruments, Inc.
2500 Harbor Boulevard
Fullerton, California 92634
(714)871-4848

Bendix Corporation
A&M Division
Box 893
Dayton, Ohio 45401
254-5377

Bendix, Scientific Instruments
Box 68
Ronceverte, West Virginia 24970
(304)647-4358

Bristol Company
Bristol Road
Waterbury, Connecticut 06720
(203)756-4451

Calibrated Instruments, Inc.
17 West 60th Street
New York, New York 10023
(212)245-5590

Conrad, Inc.
141 Jefferson Street
Holland, Michigan 49423
(616)392-3161

Control Equipment Corporation
19 Kearney Road
Needham Heights, Massachusetts
(617)444-7550

Devco Engineering, Inc.
36 Pier Lane
Fairfield, New Jersey 07006
(201)228-0321

Electro-Neutronics, Inc.
4069 Hollis Street
Emeryville, California
(415)654-1595

Ellison Instrument Division
New Buffalo
Michigan 49117
(616)469-0110

Foxboro Company
Foxboro
Massachusetts 02035
(617)543-8750

Gelman Instrument Company
600 South Wagner Road
P. O. Box 1448
Ann Arbor, Michigan
(313)665-0651

General Precision
Industrial Controls
6511 Oakton Street
Morton Grove, Illinois

Giannini Controls Corporation
330 Madison Avenue
New York, New York 10017
(212)687-3330

Gourdine Systems, Inc.
112 Naylon Avenue
Livingston, New Jersey

Hagan Controls Corporation
Box 11606
Pittsburgh, Pennsylvania 15228
(412)563-6120

Heat Systems Company
79 Broad Hollow Road
Melville, New York 11746

Hoffman Industries
Division of Belson Corporation
103 Fourth Avenue
New York, New York 10003
(212)OR7-3600

Houston Atlas, Inc.
7004 Long Point Road
Houston, Texas 77024
(713)686-7966

Industrial Nucleonics
650 Ackerman Road
Columbus, Ohio 43202
(614)267-6351

Industrial Development Company
11455 Newton Square, South
Reston, Virginia 22601
(703)471-4070

Johnson-March Corporation
3018 Market Street
Philadelphia, Pennsylvania 19104
(215)222-1411

Loenco, Inc.
2092 N. Lincoln Avenue
Altadena, California 91001
(213)681-3539

Litton Industries
Applied Science Division
2003 East Hennepin Avenue
Minneapolis, Minnesota 55413

Luft Instruments, Inc.
Old Winter Street
Lincoln, Massachusetts 01773
(617)259-9215

Mast Development Company
2212 East 12th Street
Davenport, Iowa 52803
(319)323-9729

MCI, Inc.
2324 1st Street
Livermore, California 94550
(415)447-6132

Mine Safety Appliances Company
201 North Braddock Avenue
Pittsburgh, Pennsylvania 15208
(412)241-5900

Moog, Inc.
44 Hamburg Street
East Aurora, New York 14052
(716)652-0220

Pangborn Corporation
Hagerstown
Maryland 21740

Perkin-Elmer Corporation
754 Main Avenue
Norwalk, Connecticut 06852
(203)762-1000

Phoenix Precision Instrument Company
3803-5 North Fifth Street
Philadelphia, Pennsylvania
BA8-7417

Precision Scientific Company
3737 West Cortland Street
Chicago, Illinois 60647
CA7-2660

Process Analyzers, Inc.
6400 Southwest Freeway
Houston, Texas 77036
(713)782-0820

Research Appliance Company
Route 8 and Craighead Road
Allison Park, Pennsylvania
(412)961-0588

Royco Instruments, Inc.
440 Olive Street
Palo Alto, California
(415)DA6-1831

Schneider Instruments Company
8115 Camargo Road
Madeira, Ohio 45243
(513)561-6803

Schoeffel Instrument Company
15 Douglas Street
Westwood, New Jersey 07675
(201)664-7263

Scientific Industries, Inc.
220-05 97th Avenue
Queens Village 29, New York
(212)SP6-5757

Standard Instrument Corporation
115 5th Avenue
New York, New York 10003
(212)673-3311

Staplex Company
777 5th Avenue
Brooklyn, New York 11232
(212)768-2335

Taluy Corporation
6290 Sunset Boulevard
Los Angeles, California 90028
(213)461-9416

Technical Operations, Inc.
South Avenue
Burlington, Massachusetts 01803
272-2000

Technicon Instrument
Ardsley
New York 10502
(914)693-1000

Technology, Inc.
7400 Col. Glenn Highway
Dayton, Ohio 45431
(513)426-2405

Torit Corporation
1133 Rankin Street
St. Paul, Minnesota 55116
(612)698-0391

Trion, Inc.
1000 Island Avenue
McKees Rocks, Pennsylvania 15136

Union Industrial Equipment Corporation
150 Cove Street
Fall River, Massachusetts 02720
(617)673-5811

UOP - Aerotec
Air Correction Division
Greenwich, Connecticut 06831

U. S. Automatics Corporation
627 Capitol Drive
Pewaukee, Wisconsin 53072
(414)691-1121

Varian Associates
611 Hansen Way
Palo Alto, California 94303
(415)326-4000

Western Scientific Associates
Box 698
Danville, California 94526
(415)837-4622

Wheelabrator Corporation
1521 S. Byrkit Street
Mishawaka, Indiana 46544
255-2141

Wilkens-Anderson Company
4525 West Division Street
Chicago, Illinois 60651
(312)384-4433

Ray-O-Vac Company
Willson Products Division
1985 Janice Avenue
Melrose Park, Illinois 60160
626-4755

Appendix E

DESCRIPTION OF ELECTRONIC FUNCTIONS

DESCRIPTION OF ELECTRONIC FUNCTIONS

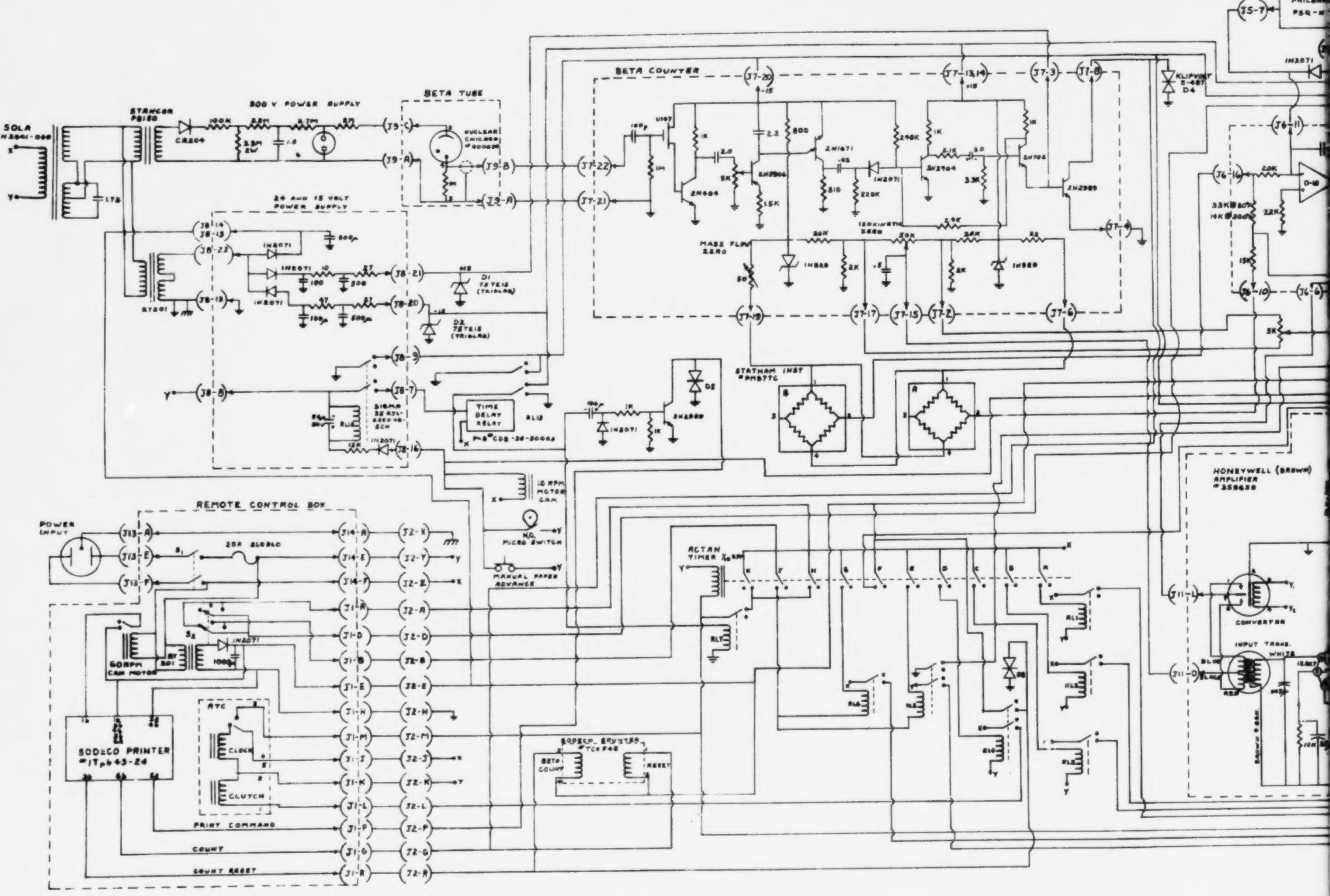
INTRODUCTION

The electronic schematic for the instrumentation is shown in Figure 1. The entire control and data handling system can be considered as 5 functional blocks. These are discussed from an operational viewpoint in the following sections.

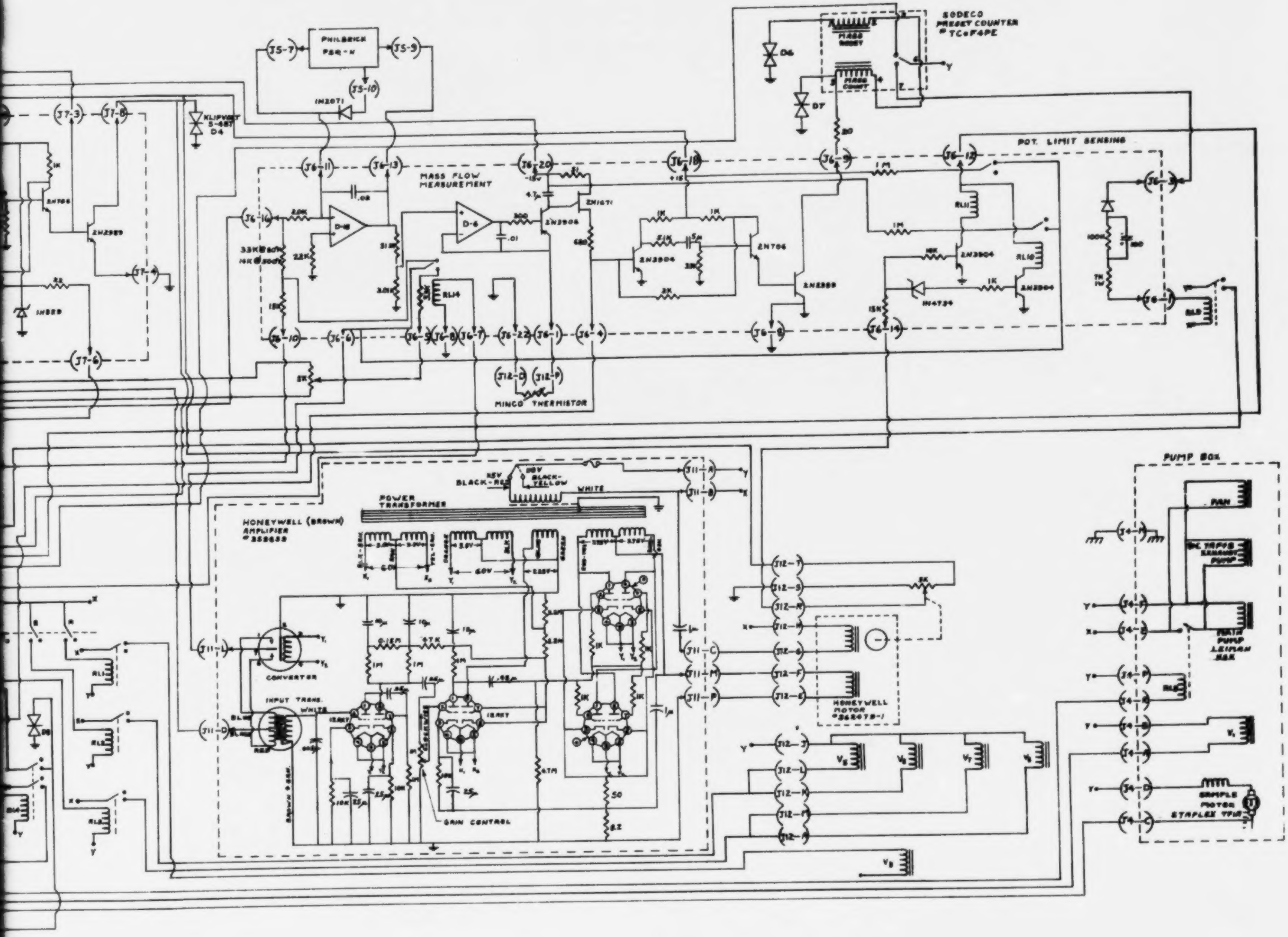
1. SEQUENTIAL CONTROL FUNCTIONS

A time interval between sampling cycles is dialed into the ATC timer in the remote control module. At the end of the interval the Actan program timer will start. The recirculation is started and the air flow system is switched to forward flow. If the mode selector switch S2, in the remote control module is either in the "isokinetic only" or in the "both" position, isokinetic sampling is initiated by energizing RL6. If the function switch is in the "fixed velocity" position, isokinetic sampling is skipped. When the mass counter count reaches zero, RL6 de-energizes, the filter tape advances, and the beta count begins. This stops the program timer. At the end of the beta count the count is printed and the program timer is started again. Next, all counters are reset.

If the function switch is in the "fixed velocity" or in the "both" position, RL6 and RL14 will energize and the sampling pump will take a sample at the velocity preset on the ten-turn potentiometer. If the function switch is in the "isokinetic


SOLA
CVN2041-000
STANCOR
P8180
300 V POWER SUPPLY
CR204
100K
2.2M
3.3M 2W
1.0
4.7M
2M
BETA TUBE
NUCLEAR CHICAGO #D0002M
J9-C
J9-A
J9-B
1M
24 AND 15 VOLT POWER SUPPLY
J8-14
J8-13
J8-22
J8-21
J8-20
J8-19
J8-9
J8-7
J8-8
J8-16
1N2071
10
27
100
500
500μ
100μ
RT201
D1
7.5TE15
(TRIOLAB)
D2
7.5TE15
(TRIOLAB)
+15
-15
SIGMA
32 RJL-6000 VS-SCH
RL11
12K
TIME DELAY RELAY
RL12
P&B CDB-38-30003
BETA COUNTER
J7-20
J7-13,14
J7-3
J7-8
J7-22
J7-21
J7-4
J7-19
J7-17
J7-15
J7-2
J7-6
U107
100p
1M
1K
2N404
2.0
5K
2N2906
1.5K
2.2
800
2N1671
.05
810
220K
240K
2N2904
5.1K
3.0
3.3K
2N706
2N2989
MASS FLOW ZERO
50
1N829
30K
2K
150K INETIC ZERO
50K
.5
2.9K
2.8K
22
KLIPVOLT
3-487
D4
STATHAM INST #PM377C
B
A
D5
2N2989
10 RPM MOTOR CAM
N.O. MICRO SWITCH
MANUAL PAPER ADVANCE
REMOTE CONTROL BOX
POWER INPUT
J13-A
J13-E
J13-F
S1
20A SLOBLO
J14-A
J14-E
J14-F
J2-X
J2-Y
J2-Z
J1-A
J1-D
J1-B
J1-E
J1-H
J1-M
J1-J
J1-K
J1-L
J1-P
J1-G
J1-R
J2-A
J2-D
J2-B
J2-E
J2-H
J2-M
J2-J
J2-K
J2-L
J2-P
J2-G
J2-R
60RPM CAM MOTOR
S2
ST 201
100μ
SODECO PRINTER
#1Tpb43-24
ATC
CLOCK
CLUTCH
PRINT COMMAND
COUNT
COUNT RESET
SODECO COUNTER
#TCeF4E
BETA COUNT
RESET
ACTAN TIMER 1/10 RPM
K J H G F E D C B A
RL1
RL2
RL3
RL4
RL5
RL6
RL7
D6
PHILBRICK
PSQ-N
J5-7
J6-11
J6-14
J6-10
J6-6
20K
D-18
33K @ 80°F
14K @ 200°F
22K
15K
5K
HONEYWELL (BROWN) AMPLIFIER #358659
J11-L
J11-D
CONVERTOR
INPUT TRANS.
WHITE
BLUE
BLACK
RED
BROWN
10K
X
Y

A


PHILBRICK
PSR-N
J5-7
J5-9
J5-10
1N2071
KLIPVOLT
5-487
D4
J7-3
J7-8
J7-4
J7-6
2N706
2N2989
1N329
SODECO
PRESET COUNTER
#TCeF4PE
MASS
RESET
MASS
COUNT
D6
D7
Y
Z
20
POT. LIMIT SENSING
MASS FLOW
MEASUREMENT
J6-11
J6-13
J6-20
J6-18
J6-9
J6-12
J6-16
J6-3
J6-10
J6-6
J6-5
J6-8
J6-7
J6-22
J6-1
J6-4
J6-2
J6-14
.02
20K
D-18
D-6
33K@80°F
14K@500°F
22K
511K
301K
300
.01
4.7μ
-15v
+15
81
2N1671
2N3906
680
1K
21K
5μ
2N3904
2N706
2N2989
1M
RL11
RL10
RL14
RL9
10K
1N4734
15K
100K
5K
J12-D
J12-P
MINCO THERMISTOR
HONEYWELL (BROWN)
AMPLIFIER
#356633
POWER
TRANSFORMER
BLACK-RED
BLACK-YELLOW
WHITE
J11-A
J11-B
J11-C
J11-M
J11-P
J11-L
J11-D
CONVERTER
INPUT TRANS.
12AX7
GAIN CONTROL
J12-T
J12-S
J12-R
J12-H
J12-G
J12-F
J12-E
J12-J
J12-L
J12-K
J12-M
J12-A
HONEYWELL
MOTOR
#362079-1
PUMP BOX
FAN
MAIN
PUMP
LEIMAN
BOX
J4-F
J4-E
J4-P
J4-R
J4-B
J4-A
J4-D
J4-C
RL6
V1
V5
V6
V7
V8
V3
SAMPLE
MOTOR
STAPLEX TFIA
X
Y

only" position, this function will be skipped. The sampling pump will continue to run until the mass counter count reaches zero. RL6 de-energizes, the filter tape advances, a beta count is taken and printed, and the solenoid valves are energized to allow air to be pumped back through the system to clean the probe and pitot lines. The counters are then reset, the recirculation pump turned off, and the ATC clock is restarted, to count-down the preset interval.

2. ISOKINETIC FLOW

Two strain gauge pressure transducers are used in the isokinetic flow loop. One transducer measures the stack velocity, the other measures the sampling velocity. Their outputs are summed and the error voltage developed is fed to a Brown Continuous Balance amplifier. This amplifier chops the DC error voltage, amplifies it, and feeds it to a control motor that drives a valve closure to vary the sampling velocity. The motor rotates in the direction dictated by the polarity of the error voltage to reduce the error voltage to zero. The speed of rotation is proportional to the magnitude of the error voltage.

The motor is connected to a position indicating potentiometer. The potentiometer output goes to two 2N3904 transistors. One transistor de-energizes RL11 when the potentiometer is near one end of its travel. The other transistor energizes RL10 when the potentiometer is near the other end of its travel. When input voltage. That is:

$$e_o = K \log e_i$$

where e_o is the output voltage, and K is a constant, and where e_i is the input voltage.

The other operational amplifier, D6, in conjunction with the 2N3906 transistor, form a current source for the thermistor and the 4.7 μ f capacitor. The charging rate of the 4.7 μ f capacitor is determined by the resistance of the thermistor and the logarithm of the input voltage. When the capacitor voltage reaches the breakdown voltage of the unijunction transistor (2N1671) the capacitor is discharged through the transistor. A resultant pulse in the base of the unijunction triggers a one shot multivibrator to produce a 200 msec. pulse. Each pulse, therefore, represents one unit of sampled mass. This is amplified by a 2N2989 transistor. The 2N2989 collector is connected to the mass counter coil through a 20 Ω resistor. A Klipvolt suppressor in the collector lead reduces inductive surges to prevent transistor damage.

The mass counter is preset to some arbitrary number. Each 200 msec. pulse triggers the mass counter to reduce the preset count by one. When the counter reaches zero, the normally open contacts on the counter close to energize RL9 momentarily. Relay 9 starts the 10 rpm motor for paper advance and de-energizes RL12 which in turn de-energizes RL13. The filter tape advance motor turns one complete revolution by the

RL11 is de-energized or RL10 is energized another signal is fed to the summing point to reverse the direction of rotation of the motor. This acts to limit the number of turns the motor can make in one direction. The valve is always in a free position and will not jam.

3. FIXED VELOCITY FLOW

Fixed velocity flow operates very similar to isokinetic flow except the stack velocity measuring transducer is replaced with a ten-turn potentiometer. The output voltage of the potentiometer establishes a fixed stack velocity. The potentiometer voltage output is then summed with the output voltage from the sampling velocity transducer. The operation then proceeds as described above.

The ten-turn potentiometer is introduced into the circuit by RL14. This relay is energized by contactor F on the cam timer and by the mode selector switch in the remote control module set to the "fixed" velocity or "both" position.

4. MASS COUNT

The sampling velocity is measured by a strain gauge pressure transducer connected across a length of the first probe section. The voltage output from the transducer is fed to a D-18 operational amplifier with a PSQ-N transconductor in its feedback network. The combination forms a logarithmic amplifier such that the output voltage is proportional to the cam action of the motor on the microswitch. At the end of the revolution, the microswitch opens, RL9 has de-energized prior to this, RL12 energizes again, and RL13 starts its time delay. The time delay relay permits the beta counter to count for a fixed time interval. The Actan cam timer is stopped by energizing RL7. At the end of the beta counting interval, set by the time delay relay, the beta counter is stopped by grounding the beta counter amplifier input, J7-3.

5. BETA COUNTER

The Beta counter measures the number of beta rays passing through the filter paper, records the count on paper tape at the remote readout/control module and indicates the count on a totalizing counter in the sampling analyzer module.

A 900 volt power supply is connected to the beta counter tube (Nuclear Chicago type 000034) through a one megohm resistor. Every beta ray that enters the detector produces a short burst of current. The current appears as a voltage across the 1 megohm resistor. The voltage is applied to a MOSFET, U147, for a current gain. The current is fed to the base of a 2N404 transistor for additional amplification. The pulse is AC coupled to a trim pot. The trim pot provides drive to a 2N3904. Each pulse from the beta tube causes a fixed quantity of current to flow through the 2N3906. This charges a capacitor in its collector lead. After 30 to 40 pulses the capacitor voltage reaches the breakdown voltage of the unijunction transistor, 2N1671. The unijunction fires, discharges, the capacitor and produces a short voltage pulse across the 510 ohm resistor in its base lead. The unijunction therefore acts as a pulse counter-divider. The unijunction output pulse triggers a one shot multivibrator consisting of two 2N706 transistors. The multivibrator produces one 200 msec pulse for each pulse output from the unijunction. The multivibrator output is amplified by a 2N2989 transistor. Two totalizing counters are paralleled in the collector lead of the 2N2989 collector level. For each pulse from the multivibrator the counters advance one digit. A voltage suppressor is connected from the collector to ground to reduce the inductive surge produced by the counters.

The beta counter continues to count until the time delay relay RL13 stops the counter by shorting the 2N2989 amplifier input at J7-3 and energizes RL7. At this time a pulse is also fed to another 2N2989 transistor through a 100 μ f capacitor. The transistor then draws current through the print coil on the printer in the remote control module and the time and beta count are printed out. A short time later the Actan cam timer resets the beta counters and the mass counter to their normal state, ready for a repeat of the whole cycle.